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THESIS

SYNOPTIC/MESOSCALE METEOROLOGICAL FEATURES IN THE MARGINAL ICE ZONE

By

Larry D. Phegley

December 1985

Thesis Advisor: Kenneth L. Davidson

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The MIZEX-84 period can be divided into three synoptic time periods. The first and the last were situations when the storms passed to the south and east of the Fram Straits. During the middle period the storms passed through the straits in response to the development of a closed upper-level low over the north coast of Greenland.

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Synoptic/Mesoscale Meteorological Features in the Marginal Ice Zone

by

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Lieutenant, United States Navy
B.S., University of Oklahoma, 1976

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND OCEANOGRAPHY

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December 1985

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Meteorological conditions occurring in the Marginal Ice Zone Experiment (MIZEX-84), conducted in the East Greenland Sea during the summer of 1984, are summarized. This recapitulation includes a discussion of the synoptic and mesoscale conditions. The three cases discussed are: a weak storm which filled over the marginal ice zone (MIZ), an intense storm which transited the MIZ and entered the polar basin, and an undisturbed case.

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I. INTRODUCTION

Increased Naval operations in the Arctic have made an understanding of the meteorology of the Marginal Ice Zone (MIZ) important. The Marginal Ice Zone is the region of transition between the totally ice covered polar ice cap and open ocean. Atmospheric forcing also impacts on the ocean and ice. In the ocean the atmosphere mixes the upper ocean altering the sound velocity profile. The atmosphere also contributes to ambient noise in the ocean and the formation and dissipation of oceanic eddies. The wind is also critical in forcing ice movement. Recent numerical experiments (Herman and Johnson, 1978) have shown that the position of the MIZ affects the long wave patterns of the polar jet stream. A lack of observations has made analyses of the synoptic and mesoscale meteorological features of the region difficult resulting in a lack of understanding of the meteorology and climatology of the area (Johnson et al, 1985). A plotting chart of the region, Fig. 1, shows the paucity of regular reporting stations in the area. The area area of the experiment is also delineated on this chart.

This lack of data requires that any investigation into the meteorology of the region rely on remotely sensed data. This is particularly true in the East Greenland Sea due to its maritime nature.

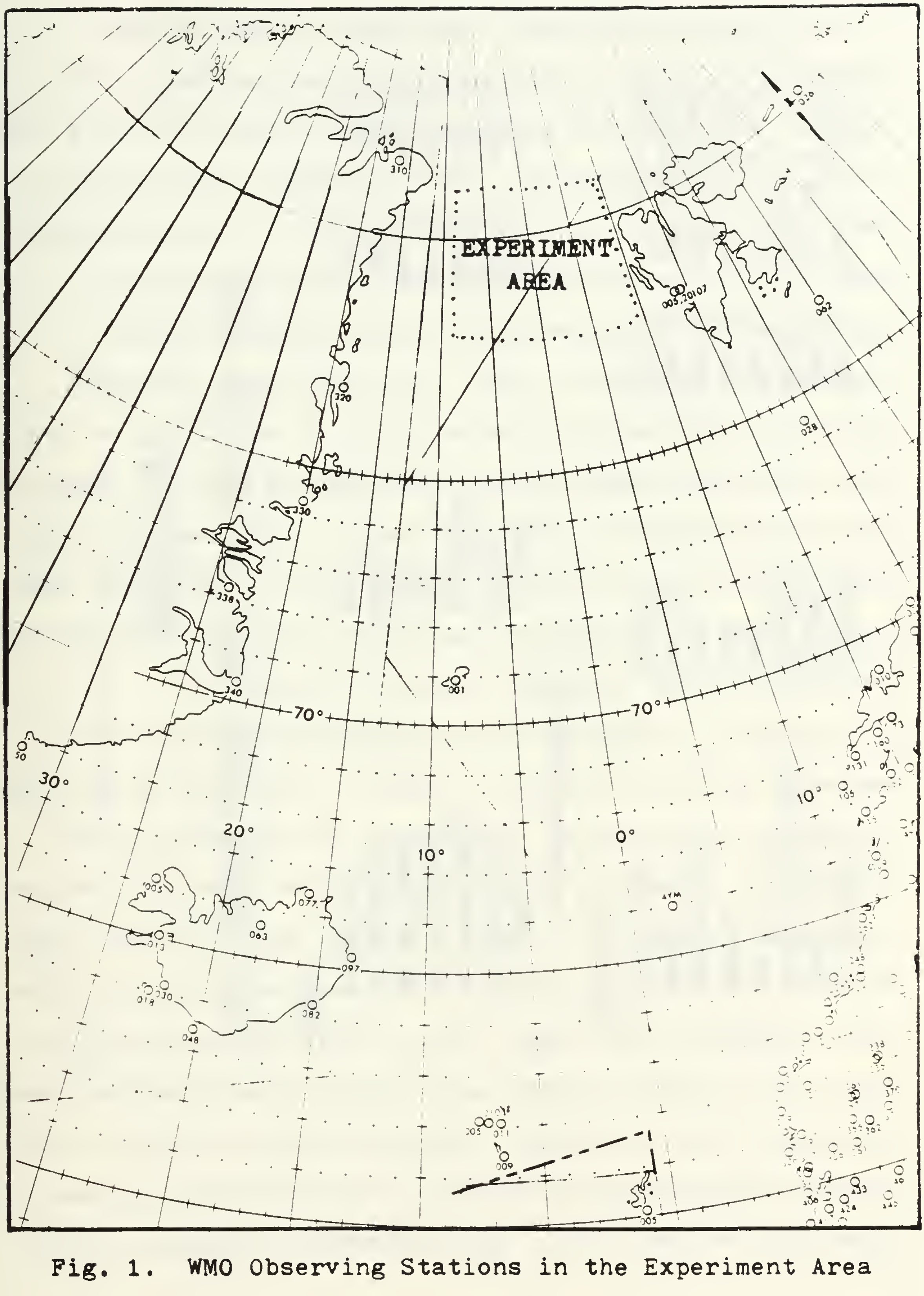


Fig. 1. WMO Observing Stations in the Experiment Area

The Marginal Ice Zone Experiment (MIZEX) of 1984 provided the first intensive observation period of this region. MIZEX-84 was conducted from 18 May to 30 July 1984 to collect meteorological, oceanographical, and acoustic data from the MIZ. The geographic area of the experiment was north and west of Spitsbergen in the Fram Strait. Participating ships and aircraft are shown in Table I (Johannessen and Horn, 1984). A pilot study, MIZEX-83, had been conducted the previous year to establish and test the experiment organization and to ensure that the temporal and spatial scales of the instrument arrays would produce the maximum amount of data (NcNitt, 1984). The experience gained from this experiment provided input for planning and execution of the increased effort of MIZEX-84.

In order to augment the existing regular observing network, the units listed in Table I were used as platforms to gather more detailed information on the state of the atmosphere. The type of observations and observing period are given in Table II. The first page of this table lists the type of observation along the side and which platforms were collecting that data. Time in days is given across the top. The time period each platform was observing these parameters are then shown. The second page shows the aircraft and buoy assets across the top and various parameters along the vertical axis. The parameters measured by each

TABLE I. Participants in MIZEX-84

(Johannessen, et al, 1984)

MIZEX 84

FIELD OPERATIONS: MAY 18—JULY 30, 1984

SHIPS:

USNS LYNCH	(NRL)	MAY 18 — JUNE 28
HU SVERDRUP	(NDRE)	JUNE 1 — JUNE 25
MV POLARQUEEN*	(PSC)	MAY 29 — JULY 29
MV KVITBJORN	(PSC)	MAY 30 — JULY 30
MS HAKON MOSBY	(U. BERGEN)	JUNE 12 — JULY 15
FS POLARSTERN*	(A.W.I.)	JUNE 11 — JULY 18
FS VALDIVIA	(U. HAMB.)	JUNE 20 — July 18

*2 HELICOPTERS ON EACH SHIP

AIRCRAFT:

CCRS CV 580	(CANADA)	JUNE 26 — JULY 8 (8 FLTS)
CNES B—17	(FRANCE)	JUNE 30 — JULY 16 (8 FLTS)
NASA CV 990	(USA)	JUNE 8 — JUNE 30 (7 FLTS)
NOAA P—3	(USA)	JUNE 20 — JULY 7 (6 FLTS)
NRL P—3	(USA)	JUNE 24 — JULY 8 (7 FLTS)
GREENLAND ICE PATROL	(DENMARK)	MAY 29 — (1 FLT)
RNAF P—3	(NORWAY)	JUNE 11 — JULY 18 (6 FLTS)
DFVLR FALCON	(GERMANY)	JUNE 22 — JULY 14 (20 FLTS)

TABLE II. Observations Taken During MIZEX-84

Day/date scale: 143 MAY 153 163 JUNE 173 183 193 JULY 203
20.22.24.26.28.30.01.03.05.07.09.11.13.15.17.19.21.23.25.27.29.01.03.05.07.09.11.13.15.17.19.21.23.25.27.29.31

Parameter	Platform		Observations
Pressure, Wind (SP, DIR), Temperature, Humidity	Polarstern		Continuous
	Polarqueen		Continuous
SFC TEMP	Lynch		wx. obs.; Continuous (Wind, Sfc Temp) wx. obs.
	Hakon Mosby		Continuous
	Valdivia		Continuous
	Kvitbjorn		wx. obs. only; Continuous
	Sverdrup		wx. obs.
	Falcon (Stratus & B. LYR)		20 24 xx xxx x xxxxx x x xx xx x
	NOAA P-3		x x x x x x
	NRL P-3A		x x x x x x
Pressure, Wind (SP, DIR),	HAM H1-H2, H2		Continuous
Temperature	BGN T1-T3 (No pressure)		Continuous
	BGN 4 (No wind)		Continuous
	BIO 2340-2342		Continuous
	BIO 2341 (Wind SP only)		Continuous
Radiosonde, Tethersonde, SODAR, Dropsonde	Polarstern (RAD & SODAR)	(249)	8
	Polarqueen (RAD & SODAR)	(120)	4 2 4 8
	Lynch (Rad)	(30)	
	Hankon Mosby (Rad & SODAR)	(136)	s
	Valdivia (Rad)	(121)	8
	Kvithjorn (Tethersonde)	(50)	on ice floes only
	NOAA P3 (Dropsonde)		

HAM-Univ. of Hamburg BGN- Univ. of Bergen BIO- Bedford Inst. of Ocean.

TABLE II. (cont)

MEASURED/DAYS	AIRCRAFT: Falcon 20 (Stratus) 7 Flights	Falcon 20 (Bounds Lyr) 13 Flights	NOAA P-3 6 Flights	NRL P-3A 6 Flights	BUOYS: Hamburg H-1	Hamburg H-2	Bedford 2340	Bedford 2341	Bedford 2342	Bergen, T-1	Bergen, T-2	Bergen, T-3	Bergen, T-4
Surface Temperature	✓	✓	✓	✓									
Mean Pressure	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓
Mean Wind (Sp, dir)	✓	✓	✓	✓	✓	✓	✓ (Spd)	✓ (Spd)	✓ (Spd)	✓	✓	✓	
Mean Temperature	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓
Mean Humidity	✓	✓	✓	✓									
Turbulent Wind	✓	✓	✓										
Turbulent Temperature	✓	✓	✓										
Turbulent Humidity	✓	✓	✓										
Radiation Long	✓	✓	✓										
Radiation Short	✓	✓	✓										
Radiation Lnng	✓	✓	✓	✓									
Radiation Short	✓	✓	✓										
Profiles: P, T, q, v	✓	✓	✓	✓									
Aerosnl .8-15μm 5-150μm	✓												
Liquid Water Content	✓		✓	✓									
Surface Roughness	✓	6/20,22,24 7/6											

platform are then marked with a check. Satellite observations complete the list of additional data available for this time frame to thoroughly describe the meteorological conditions during the experiment.

The meteorology of the MIZ differs from that of other areas. The planetary boundary layer of the MIZ is of varying depth. It is very shallow over the ice and slopes upward to a distance of several kilometers away from the ice edge. It will be shown later that a secondary storm track runs parallel to and just seaward of the ice edge. The contours of cloud coverage also run parallel to the ice edge with more clouds over the ice than over the sea.

This thesis presents the synoptic and mesoscale features observed during MIZEX-84 with emphasis on the MIZ's effect on surface wind flow and sensible weather (cloud cover and precipitation). The availability of satellite data provides an opportunity to mesh actual surface observations with the satellite imagery to obtain a complete understanding of the MIZ conditions. Imagery from the Defense Meteorological Satellite Program (DMSP) and the Advanced Very High Resolution Radiometer (AVHRR) carried aboard the NOAA-7 spacecraft are used as part of the data set for this thesis.

The surface observations and radiosonde soundings from the research vessels involved were usedto produce small scale analyses, vertical cross-sections and time series of the area. Mesoscale and synoptic scale features developing in or transiting the MIZ were detected and analyzed. For those features transiting the MIZ, the effect the MIZ has on the intensity of the feature will be examined. Finally, some conclusions are made regarding the effect of the MIZ on surface wind flow and sensible weather. Several recommendations are made which suggest a need for continued research in this area.

II. CLIMATOLOGY OF THE MARGINAL ICE ZONE

A discussion of the climatology of the region is necessary in order to compare conditions found during MIZEX and the mean. This section will present a brief overview of the climatological conditions found in the Fram Straits for June and July. It should be emphasized that there is not a large data base of observations on which to derive the climatic conditions of the area. The data for this overview came from U.S. Navy, (1963). The atlas was based on approximately 100 observations each for June and July for the Fram Straits region. Brown et al, 1984, was used to supplement this data.

A short description of the climate of the MIZ during this time of year follows. The air temperature is around freezing, frequent clouds and fog are observed, and wind is from the south at 5 m/s. With the onset of summer the average air temperature rises from -0.6 ^{o}C for June to 1.1 ^{o}C for July. The wind over the water is generally from the southeast to southwest at 5.1 m/s or less. The wind is much more variable over the ice but still generally from the southwest. In June the wind over the ice tends to come from the north or northwest about 40% of the time. The wind speed is also more variable over the ice but generally less than 7.7 m/s. The distribution of wind observations over ice and water are given in Figs. 2 and 3, respectively. Fig. 2 describes the conditions just north of Spitsbergen and Fig. 3 is for the Fram Straits south of the ice edge. The bar values are given by the top scale in the percentage of wind observations from each of the eight directions and calm. The actual number of observations for specific wind speed, bottom scale, and direction combinations are given in the boxes.

Low level cloud cover is a dominant feature in the area with 70% of all observations reporting 8/10 cloud cover or more. The cloud distribution curves, Figs. 4 and 5, show a higher probability, 20%, of less than overcast skies occurring over the ice during July. Figs. 4 and 5 are cumulative distribution curves. The value read for a desired cloud amount is the percentage of observations with that amount of cloud coverage or less. The contours of cloud amount are parallel to the ice edge with the amount decreasing away from the ice. There is also a 30% probability of visibilities of 2 n mi or less.

The July storm tracks and climatological ice edge are given in Fig. 6. The tracks in the East Greenland Sea do not vary significantly from June. The primary track is south of Iceland with a secondary track just south of Spitsbergen. These storms would be expected to be occluded cyclones traveling into the cold air. LeDrew (1984)

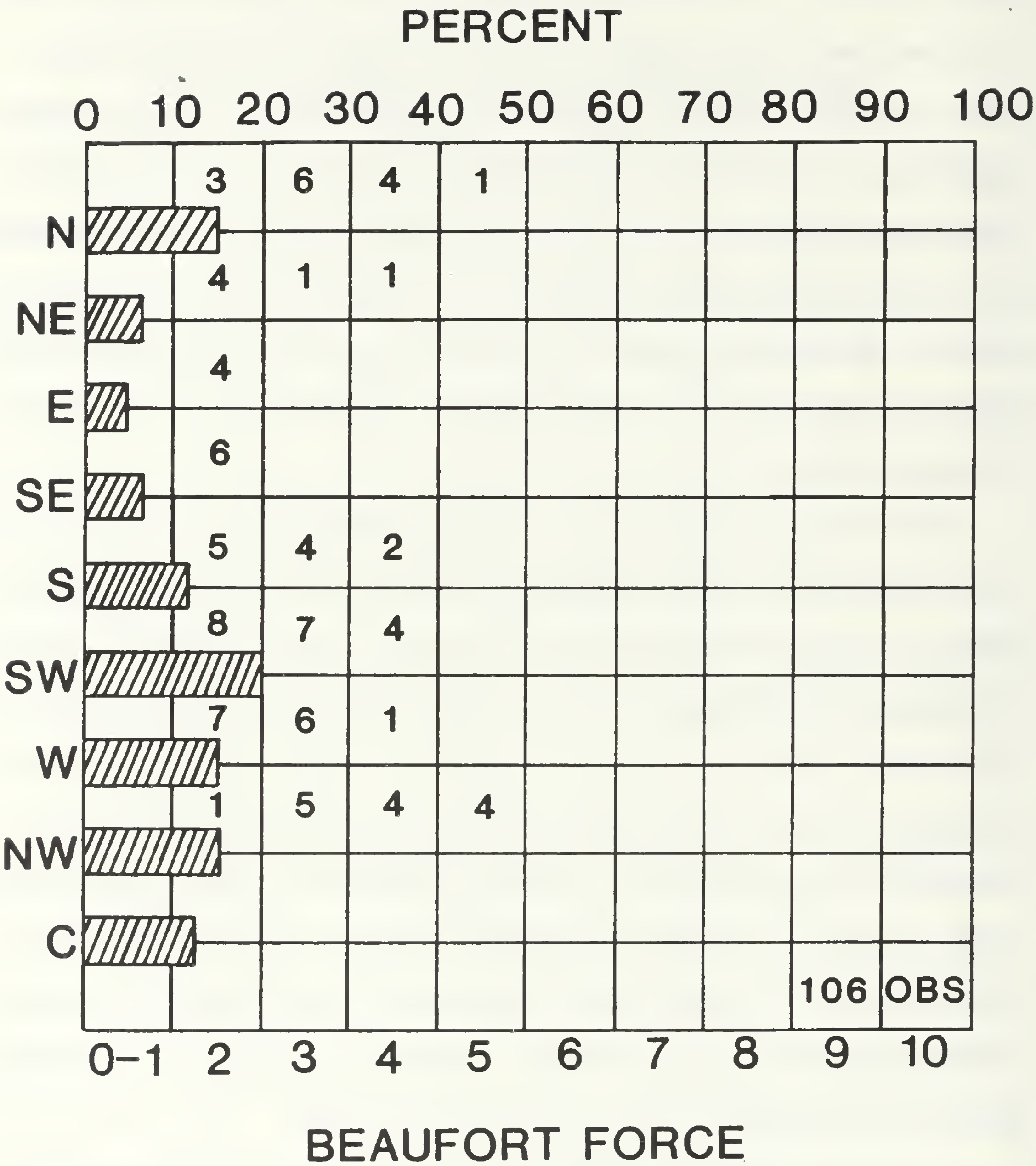


Fig. 2. Wind Observation Distribution Over the Ice (U.S. Navy, 1963)

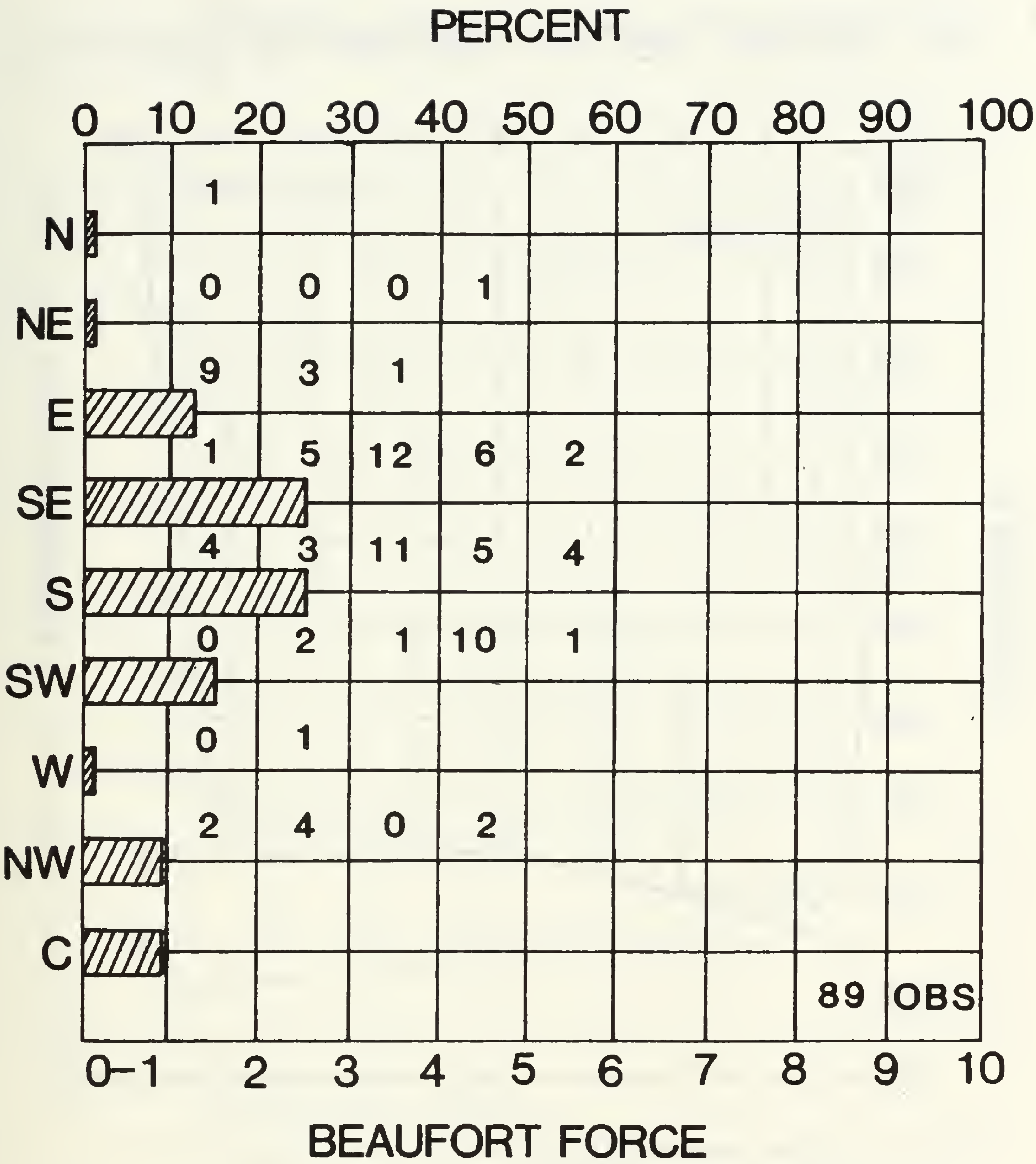


Fig. 3. Wind Observation Distribution Over the Water
(U.S. Navy, 1963)

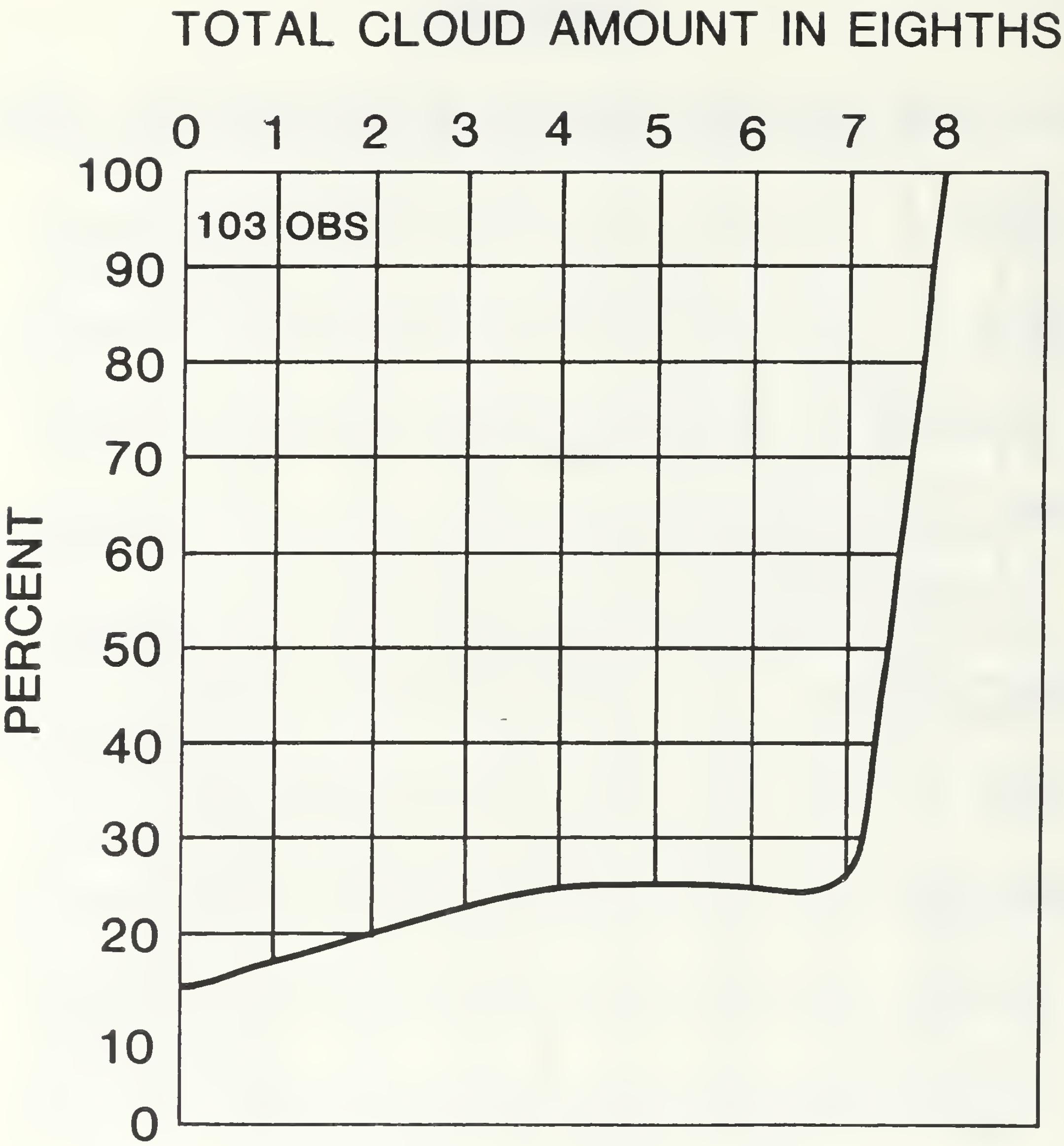


Fig. 4. Cloud Amount Distribution Over the Ice
(U.S. Navy, 1963)

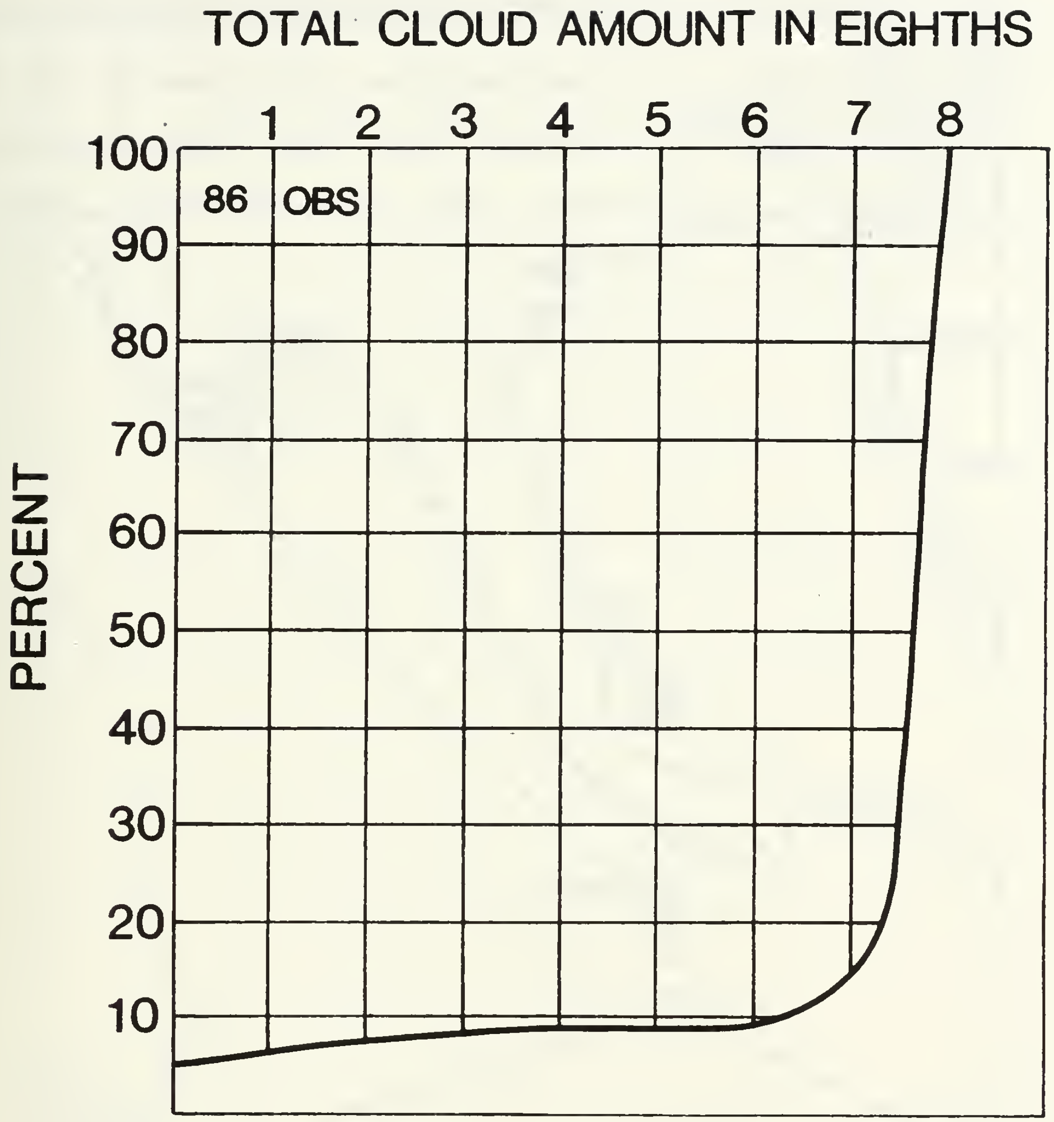
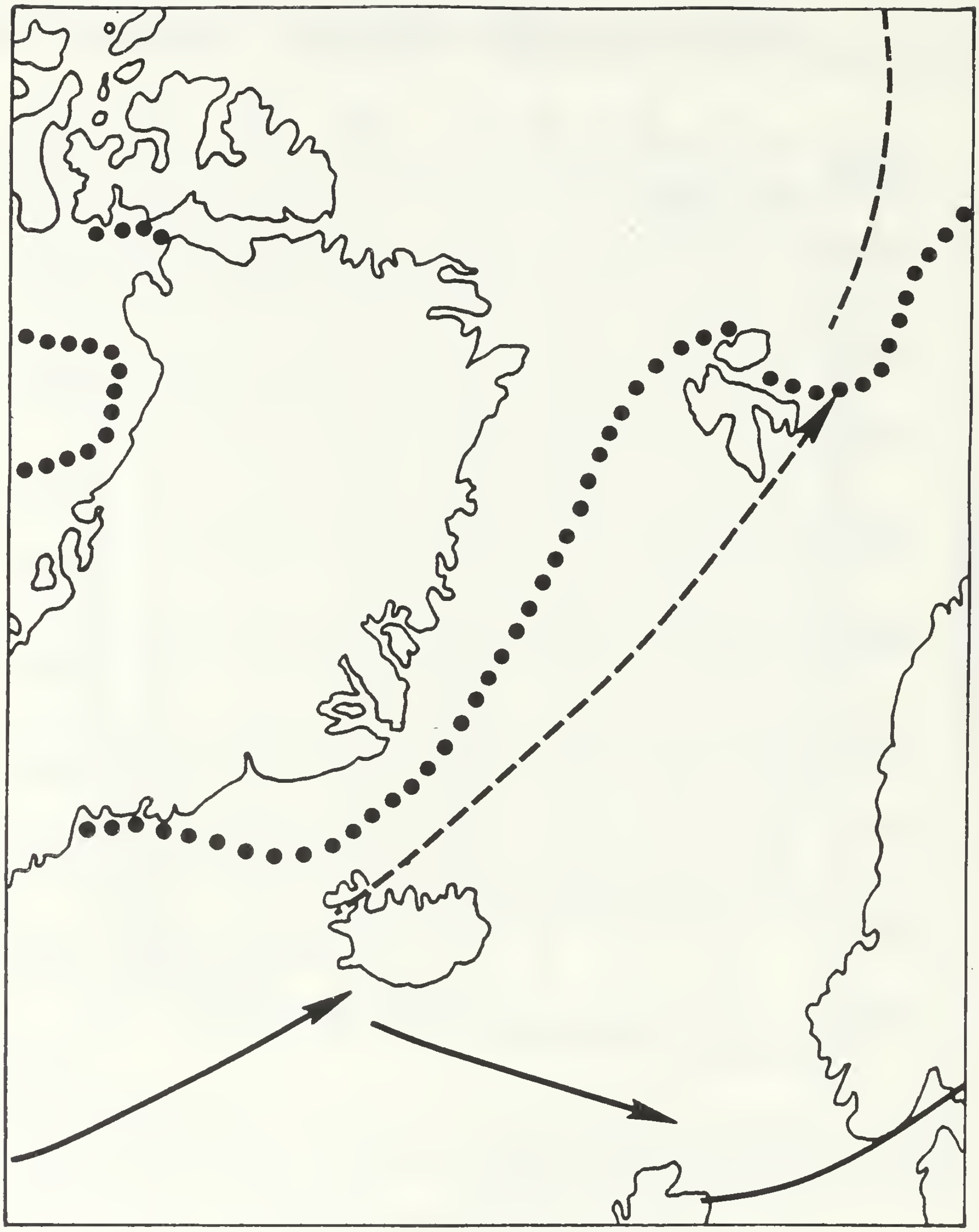


Fig. 5. Cloud Amount Distribution Over the Water
(U.S. Navy, 1963)



ICE EDGE.....

PRIMARY STORM TRACK

SECONDARY STORM TRACK

Fig. 6. Climatological Storm Tracks and Ice Edge for July (U.S. Navy, 1963)

identified this area as being the source region for 50% of the storms which entered the polar basin. Due to the warming temperatures the ice edge is slightly north of its June position (U.S. Navy, 1963)

III. SYNOPTIC OVERVIEW OF MIZEX 84

A. GENERAL

The overview is a synopsis of the surface and 500 mb analyses produced by the National Meteorological Center (NMC). It will consist of a nearly day by day description of the position, movement, and strength of synoptic-scale and mesoscale features when identified from satellite imagery. The term jet will be used to describe a gradient of 180 m per 500 km or three contours per five degrees of latitude observed on the 500 mb analysis. The contour interval on a 500 mb analysis is 60 m. This gradient corresponds to a geostrophic wind of approximately 12.5 m/s. The storm tracks displayed in the section were produced by plotting the location and pressure of the storm's center as depicted on NMC surface analyses. By comparing NMC surface analyses with reanalyzed surface pressure fields used in the next section for the case studies, it was found that the centers of synoptic features were normally well located but the actual shape and position of the contours were better defined using the additional data gathered during MIZEX-84. Analyses from the Fleet Numerical Oceanography Center (FNOC) will be presented here to help clarify the conditions on certain days.

The synoptic situation of MIZEX-84 can be broken into three time periods. In the first period (5 to 11 June 1984) occluded storms passed to the south and east of the experiment area. The participating ships sometimes experienced strong winds from the tightened gradient caused by a storm passing nearby. A typical 500 mb field for this period is presented in Fig. 7. This figure is the long wave or "SR" field from FNOC for 9 June 84 at 1200 GMT. According to U.S. Naval Weather Service (1975), this field is produced by smoothing the total field to eliminate the short waves. This chart shows the straits on the edge of an upper-level ridge extending from Iceland to Greenland and west of a low north of Norway.

This high forced the storm track to the south of Iceland. This combined with the northwesterly flow through the straits acts to keep storms out of the straits during this first period. The 1000 mb SR field, Fig. 8, shows a high centered over the east central coast of Greenland.

The second period (11 June to 1 July 1984) was a period of active weather in the straits. Storms which would have previously gone around the area now passed over or very near it. The 24 June 84 500 mb SR chart, Fig. 9, is typical of the period. It shows a closed upper-level low centered over north central Greenland and a trough extending eastward over the southern boundary of the experimental area. The storm track moved north to a position over Iceland. This

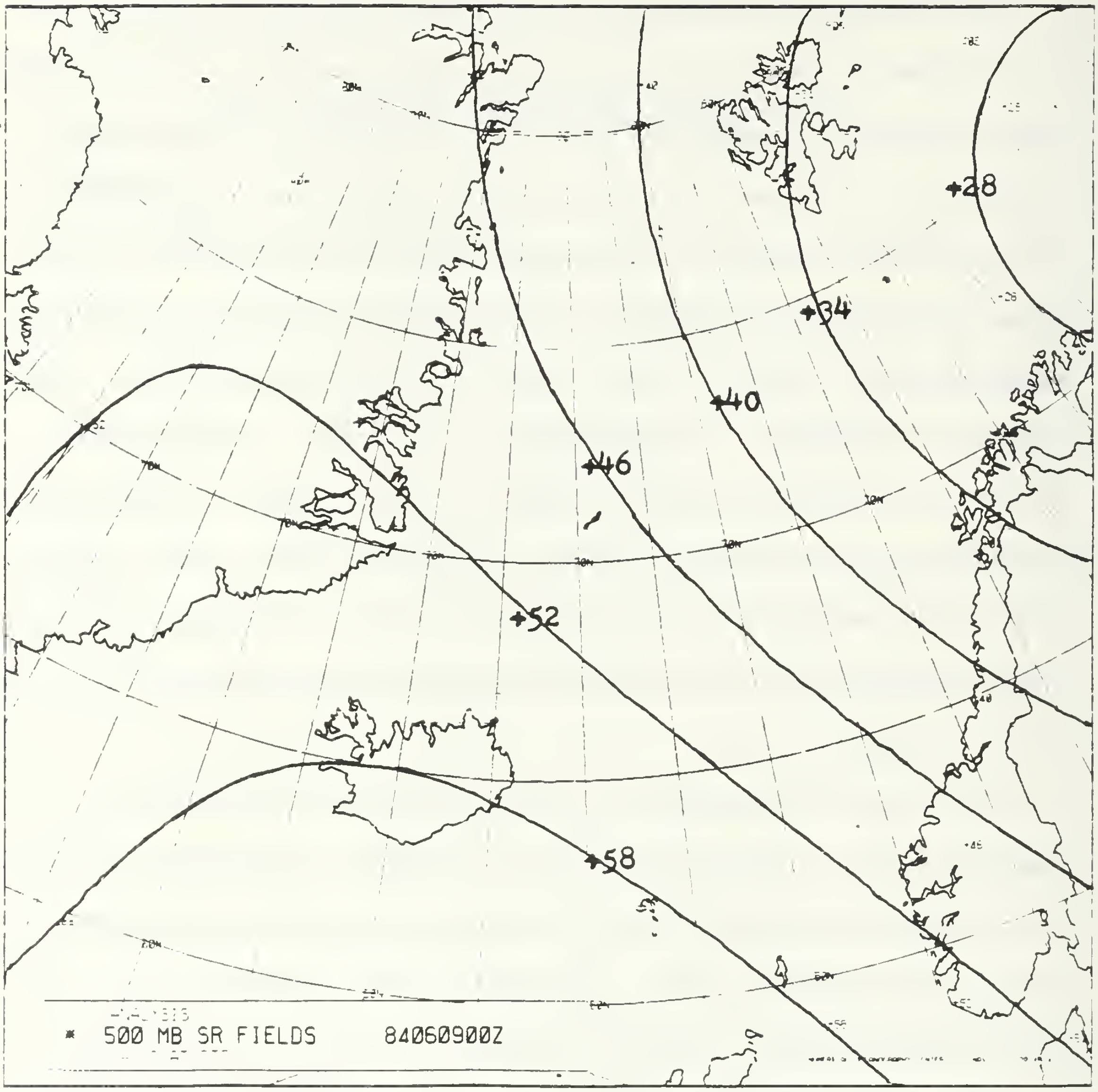


Fig. 7. 500 mb SR Field for 9 June 1984

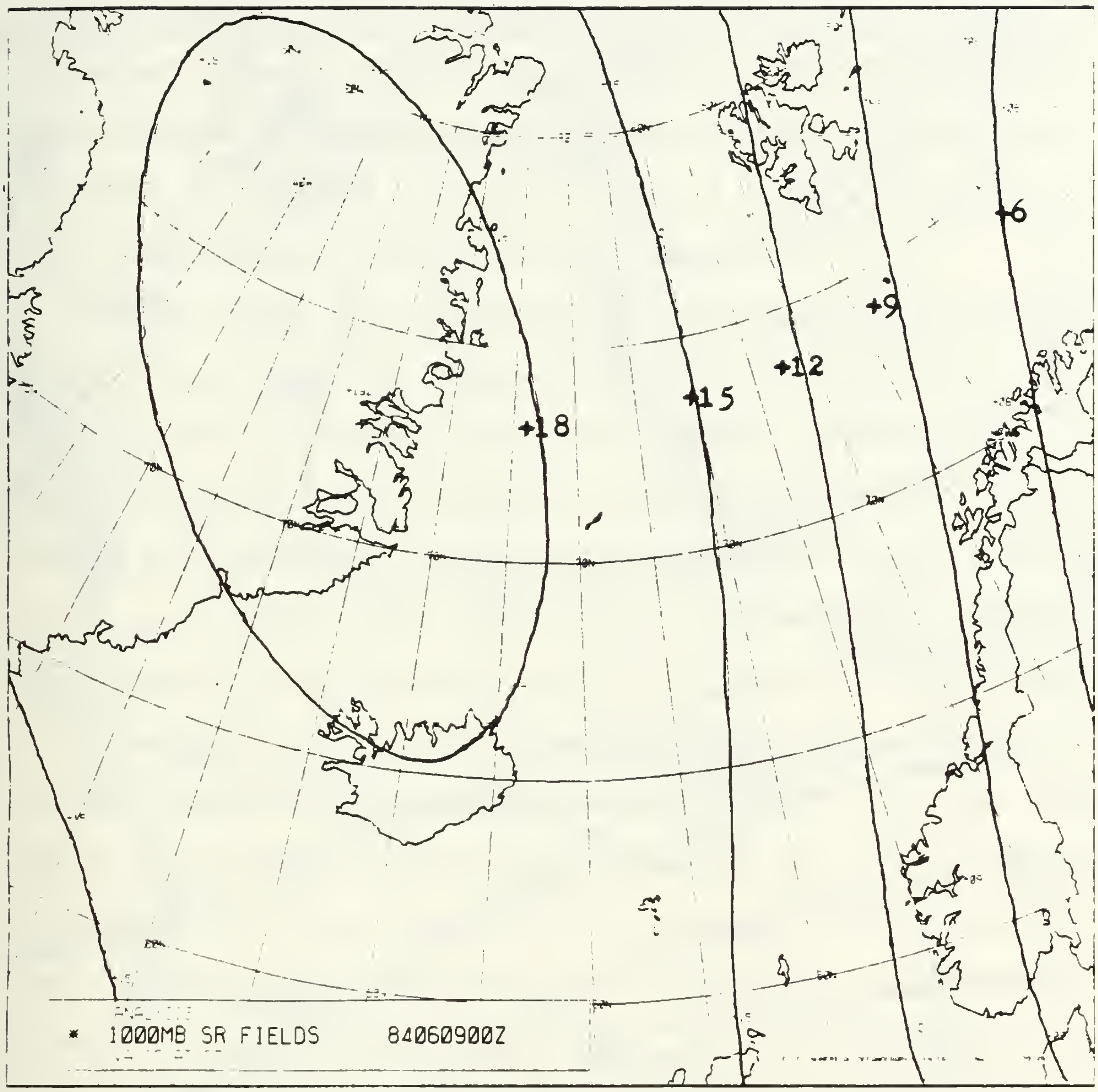


Fig. 8. 1000 mb SR Field for 9 June 1984

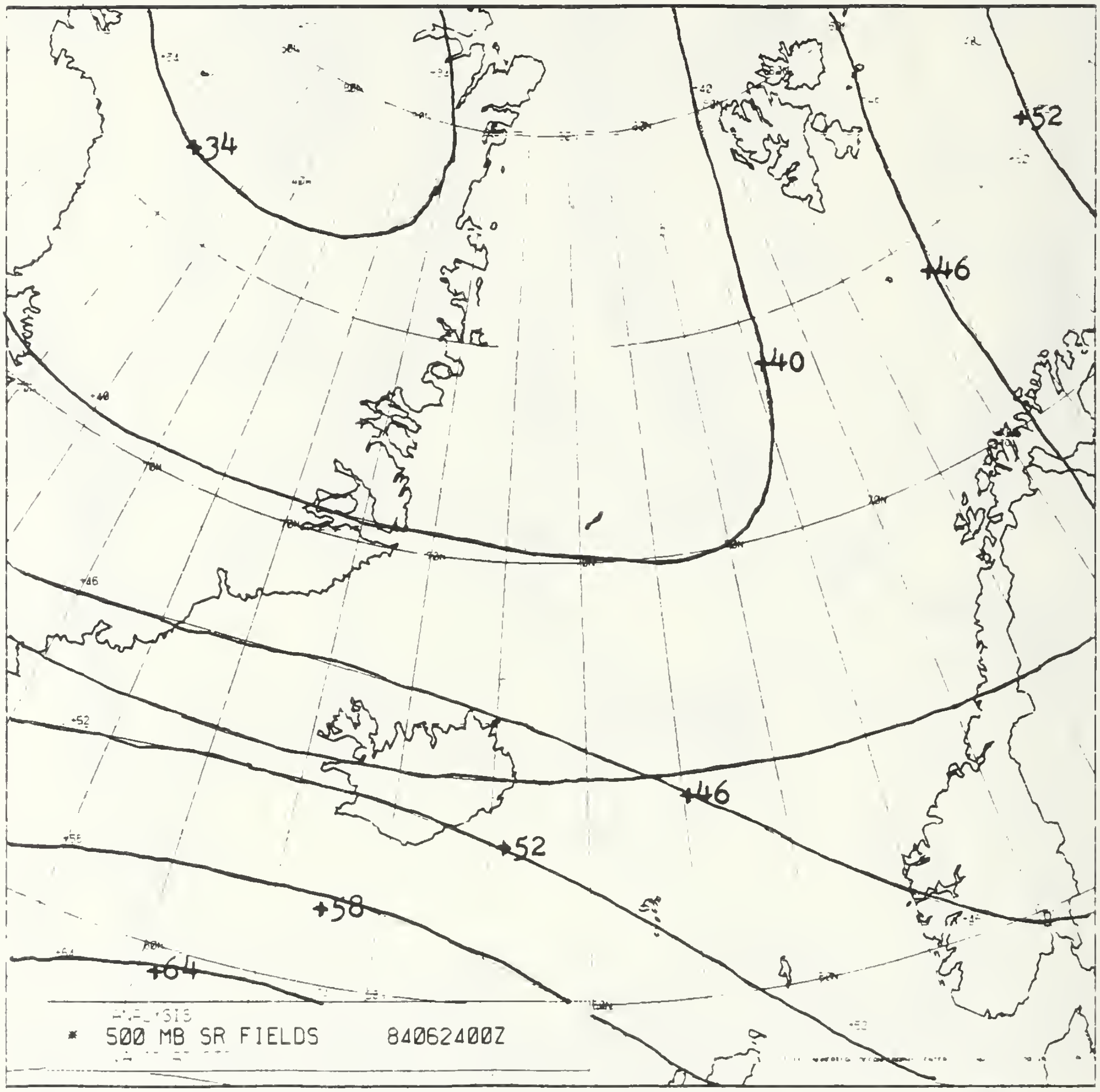


Fig. 9. 500 mb SR Field for 24 June 1984

pattern allowed storms to deviate from the typical storm track and transit northward on the east side of the upper-level vortex over Greenland directly through the straits. The 1000 mb. SR field, Fig. 10, shows a trough stretching into the southern straits from Norway.

After 1 July 84 the storms again passed around the area to the south and east. Some of the calmest winds were experienced during this final period. The SR field for 11 July 84, Fig. 11, provides an example of the 500 mb flow during this period. It shows the experiment area dominated by an upper-level high. The 1000 mb SR field, Fig. 12, also shows general high pressure at the surface.

The time series of wind speed and direction, pressure and air temperature, taken from Lindsay (1985) for the Hakon Mosby and the Polar Queen, are presented as Figs. 13 and 14, respectively. There are several peaks and valleys in both the time series and these will be associated with synoptic events in the following sections.

B. INITIAL CALM PERIOD

The initial period of the experiment, 5 to 11 June 84, was a time when the straits were dominated by high pressure. This will be termed the normal situation since it prevailed for the majority of the experiment. The 500mb and surface analyses from FNOC for 5 June 84 are presented as Figs. 15 and 16. A 1034 mb high pressure system dominated the

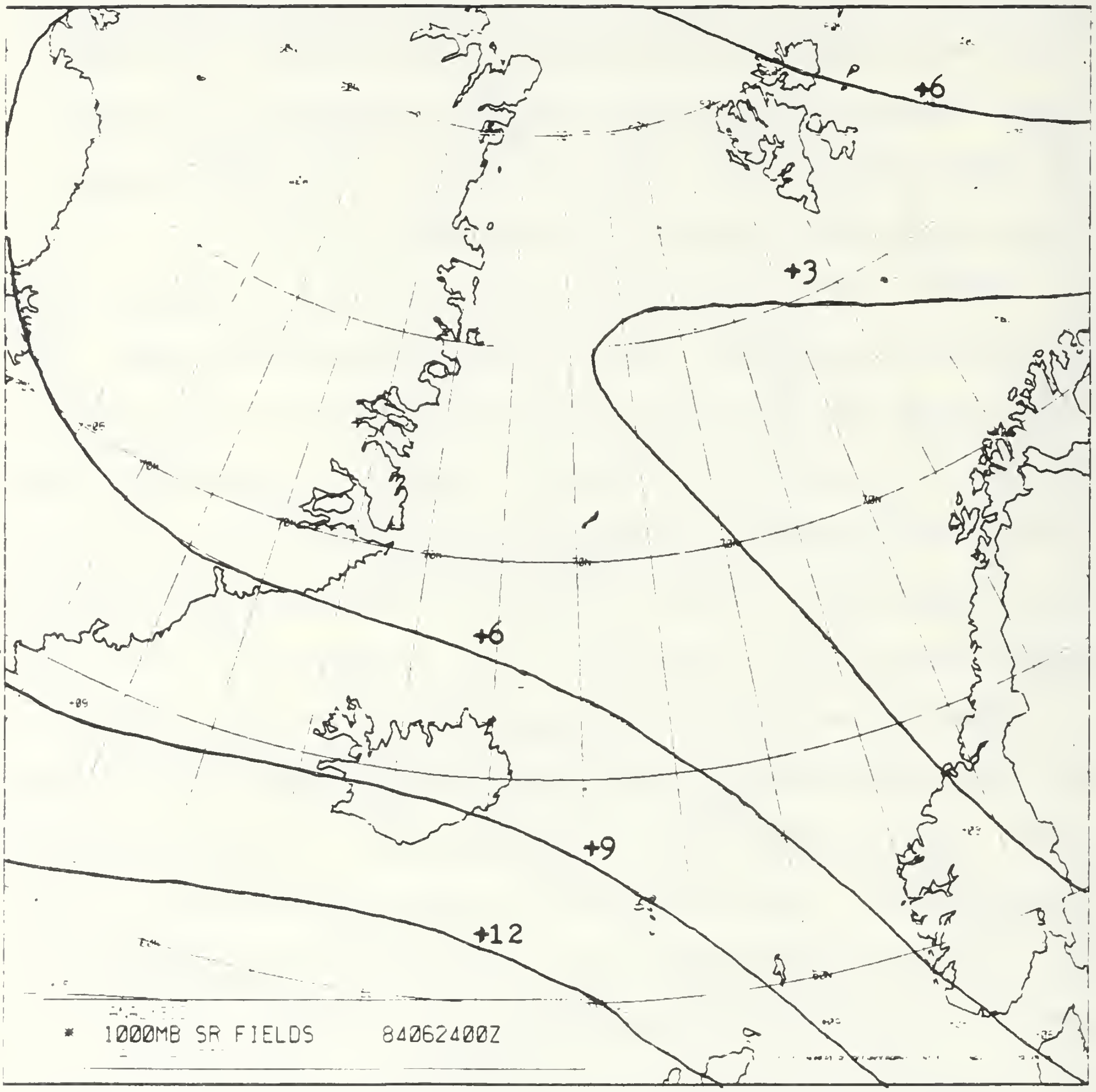


Fig. 10. 1000 mb SR Field for 24 June 1984

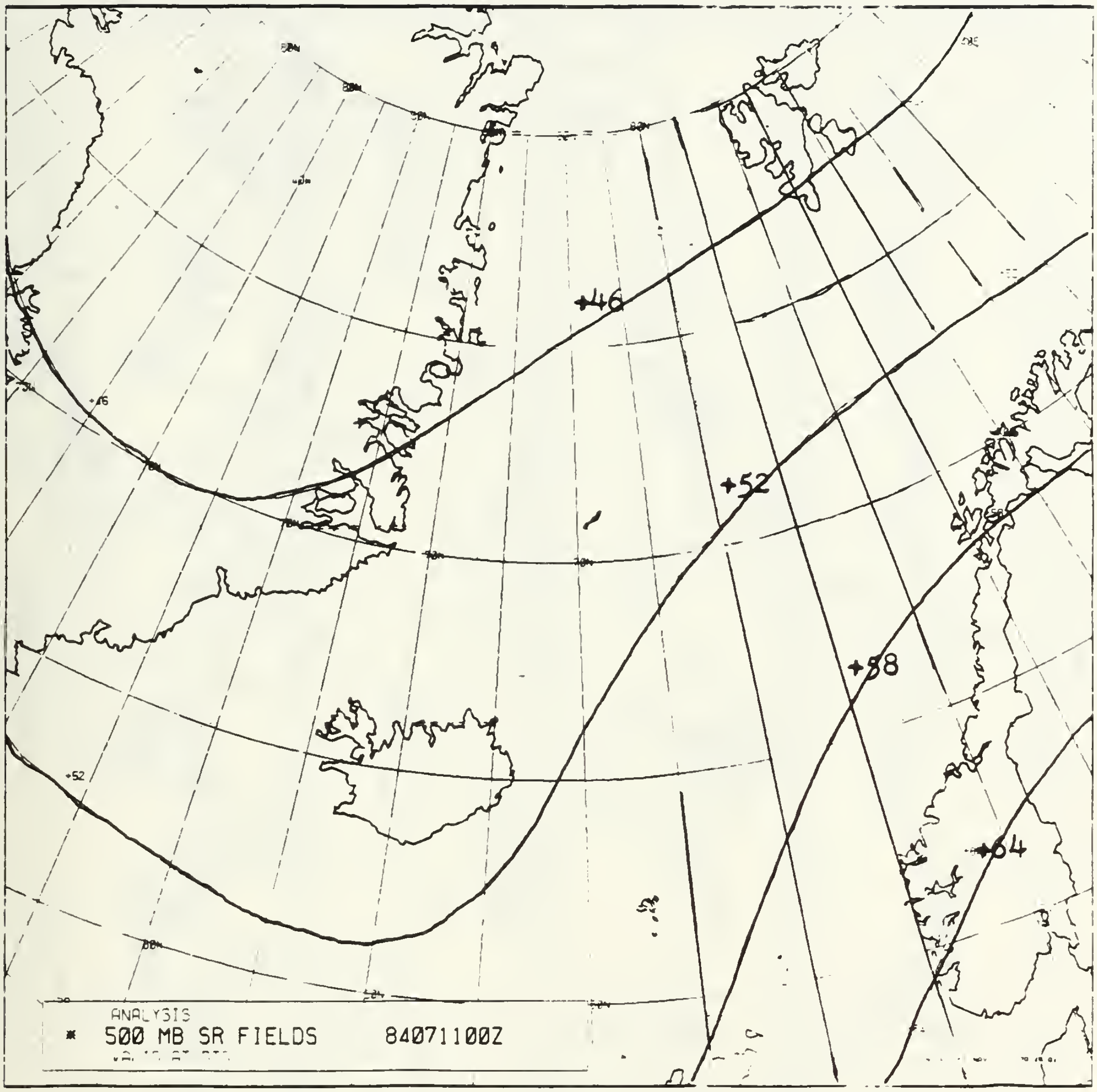


Fig. 11. 500 mb SR Field for 11 July 1984

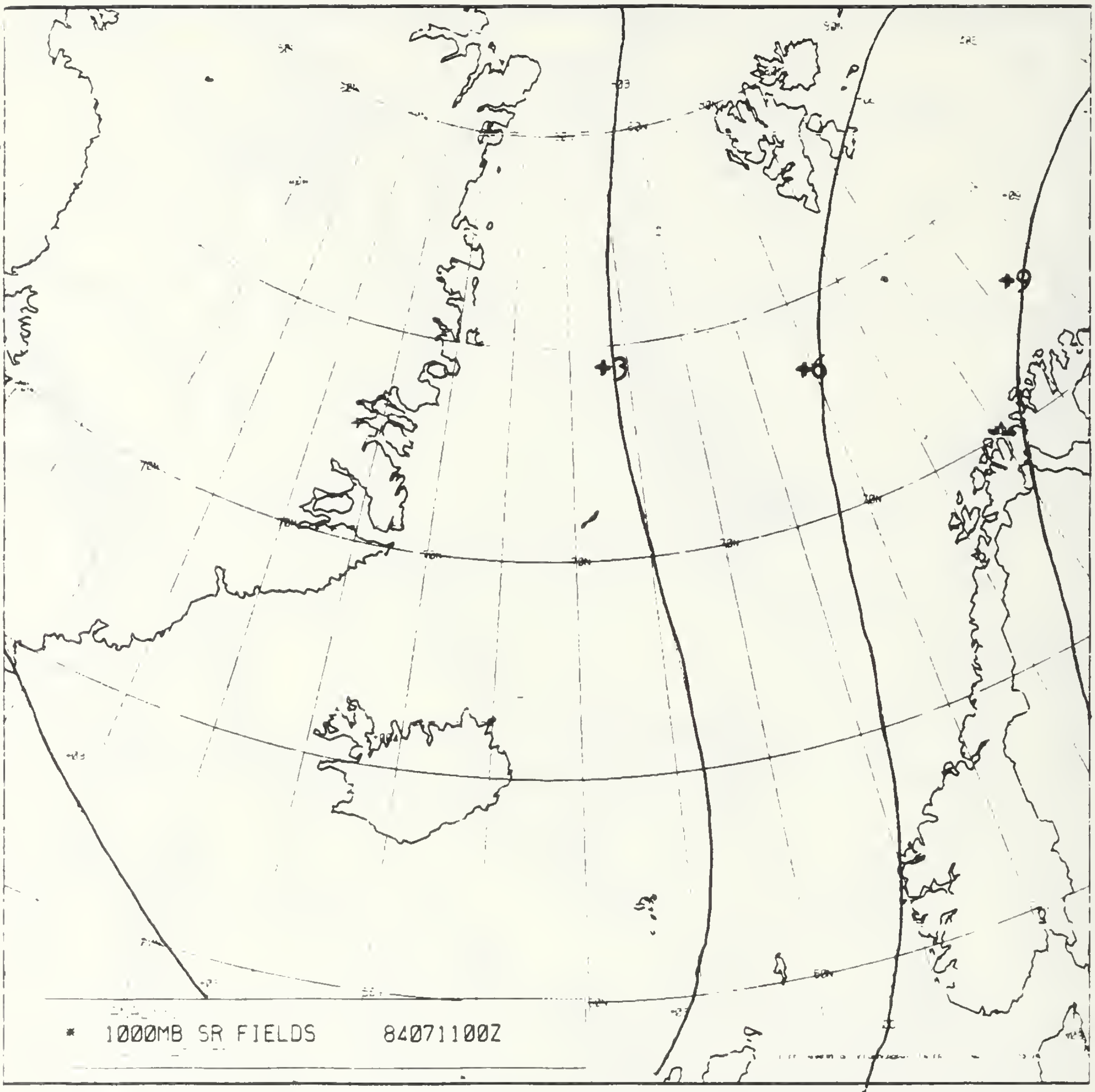


Fig. 12. 1000 mb SR Field for 11 July 1984

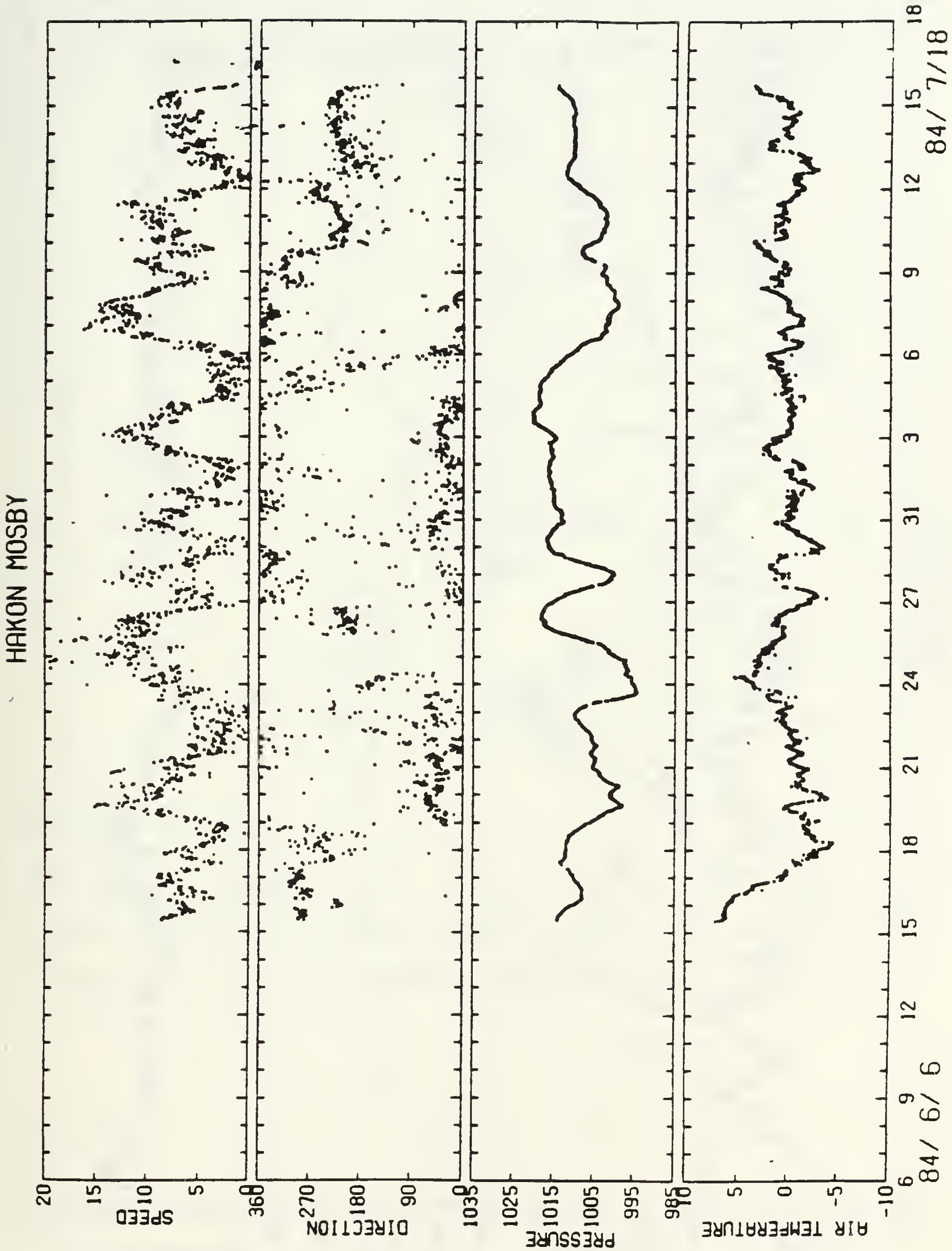


Fig. 13. Observation Time Series for the Hakon Mosby (Lindsay, 1985)

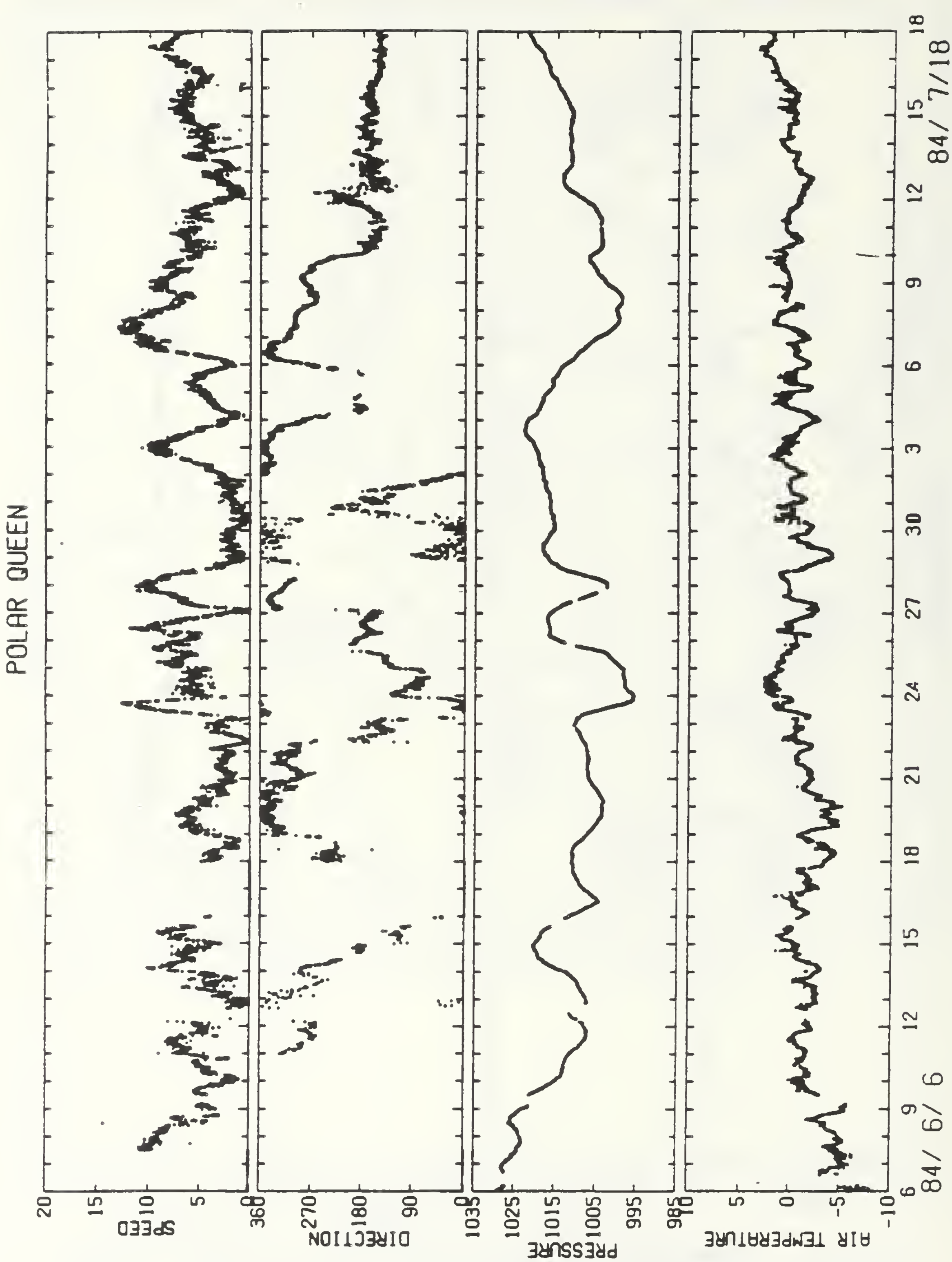


Fig. 14. Observation Time Series for the Polar Queen (Lindsay, 1985)

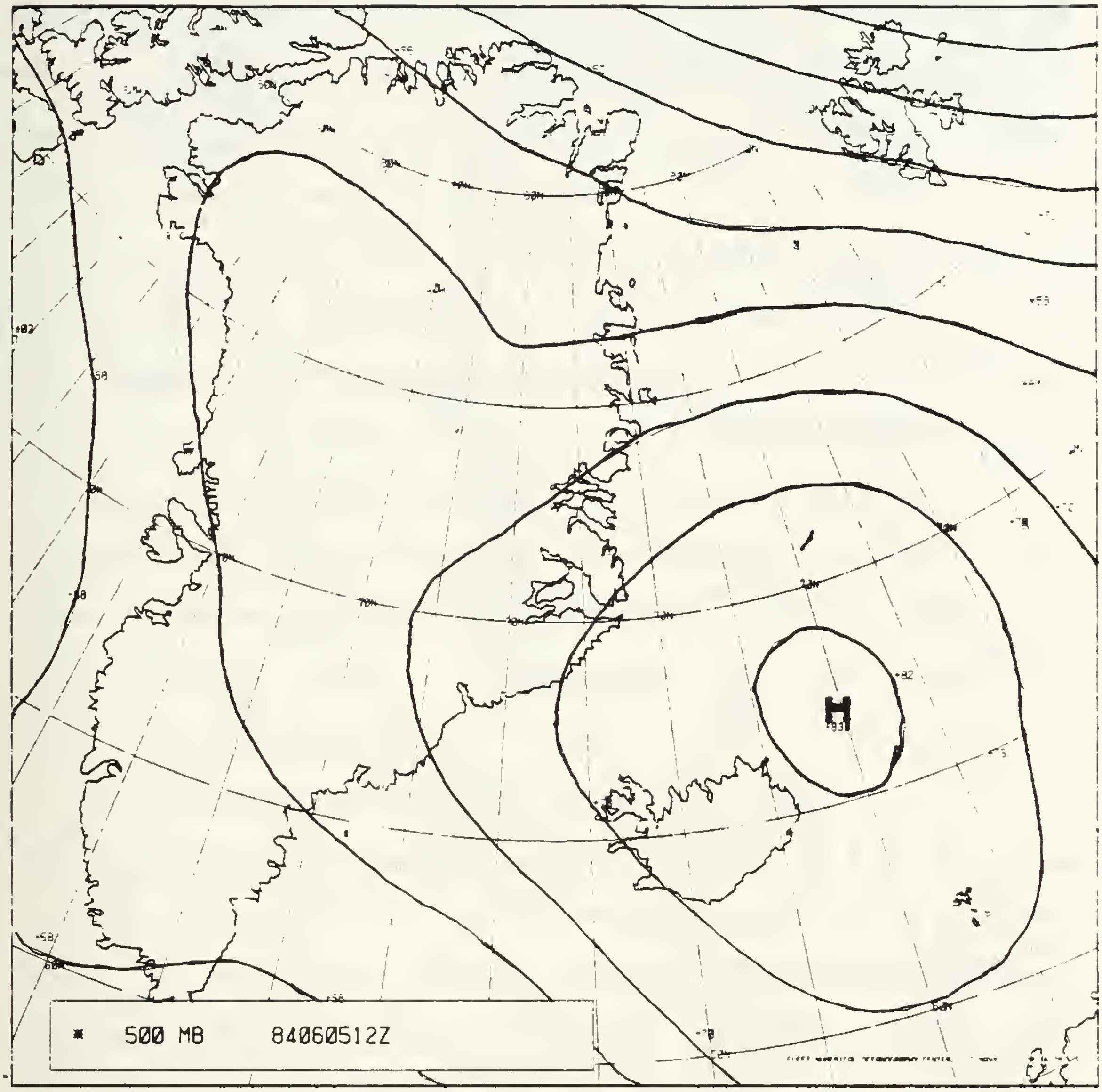


Fig. 15. 5 June 84 500 mb Analysis

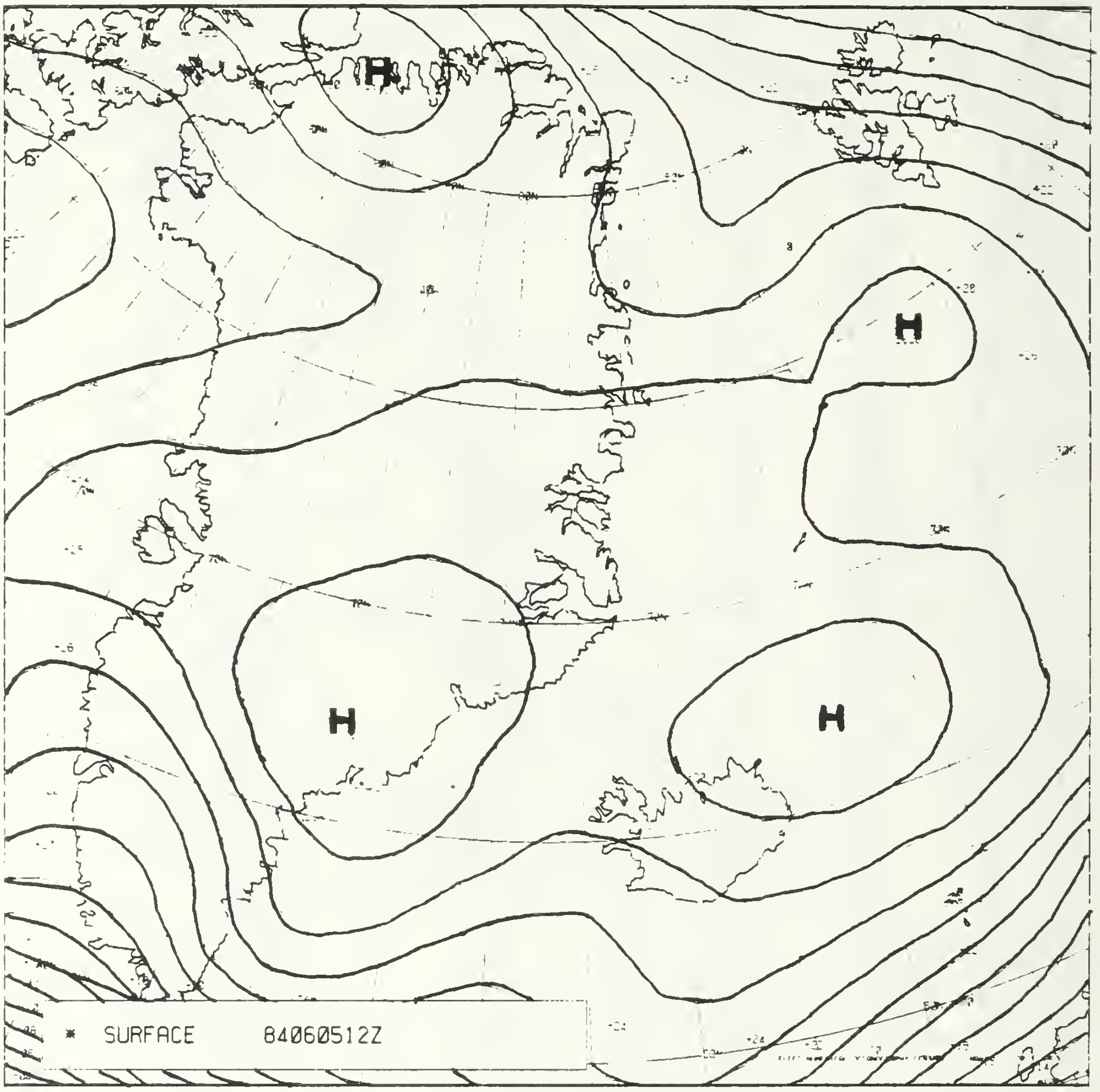


Fig. 16. 5 June 84 Surface Analysis

southeast coast of the Greenland landmass ridging into an area south of the straits. There was also an upper-level ridge located over Greenland with the jet oriented north-west-southeast over Spitsbergen.

By 6 June 84 a 1033 mb high had broken off from the high over Greenland and was located directly south of the area of the experiment. An upper-level vortex originally located over Siberia started to drift to the west. This shifting of the vortex caused the jet to take on a more north-south orientation over Spitsbergen. The surface high pressure over Greenland intensified to 1039 mb causing a tightening of the surface pressure gradient over the experiment area with a north-south orientation.

The surface gradient slackened on 7 June 84 and the upper-level high pressure began to weaken as the upper-level vortex continued to drift west. On 8 June 84 the surface high over Greenland weakened to 1034 mb and the upper-level high continued to recede. A 988 mb occluded low was located east southeast of the area and its pressure field started to influence the flow over Spitsbergen.

Both the surface high and the occluded cyclone continued to weaken on 9 June 84. The jet had also weakened and migrated to the west over the straits. On 10 June 84 another surface high broke away leaving a 1028 mb high over Greenland and a 1024 mb high just off the central east coast. The surface low moved to 80° N just east of Spitsbergen and filled to 1000 mb. A trough extended westward to near the Greenland coast.

On 11 June 84 the surface high continued to weaken to 1020 mb. The occlusion was slowly drifting westward directly over Spitsbergen with a central pressure of 1002 mb. The upper-level vortex had moved westward to just east of Spitsbergen and a weak trough extended westward to an intense low over northeast Canada. The DMSP visual imagery for 0558 GMT, Fig. 17, shows two mesoscale vortices in the straits at "A" and "B". These vortices were presumably produced by flow around Spitsbergen.

By 12 June 84 the jet was very weak and oriented east-west just south of Spitsbergen. The surface occluded low had moved into the straits and the high had weakened to 1016 mb. This situation continues until 14 June 84 when the low fills and a 1016 mb high moved up from the south into the southern portion of the straits. The FNOC 500 mb and surface analyses are shown as Figs. 18 and 19. The high over Greenland began to build to 1020 mb. The upper-level closed vortex had continued to drift west and was over the northeast coast of Greenland.

The synoptic situation of these first days of the experiment correlate well with the observations from the Polar Queen, Fig. 14. The wind speed initially was about 10 m/s

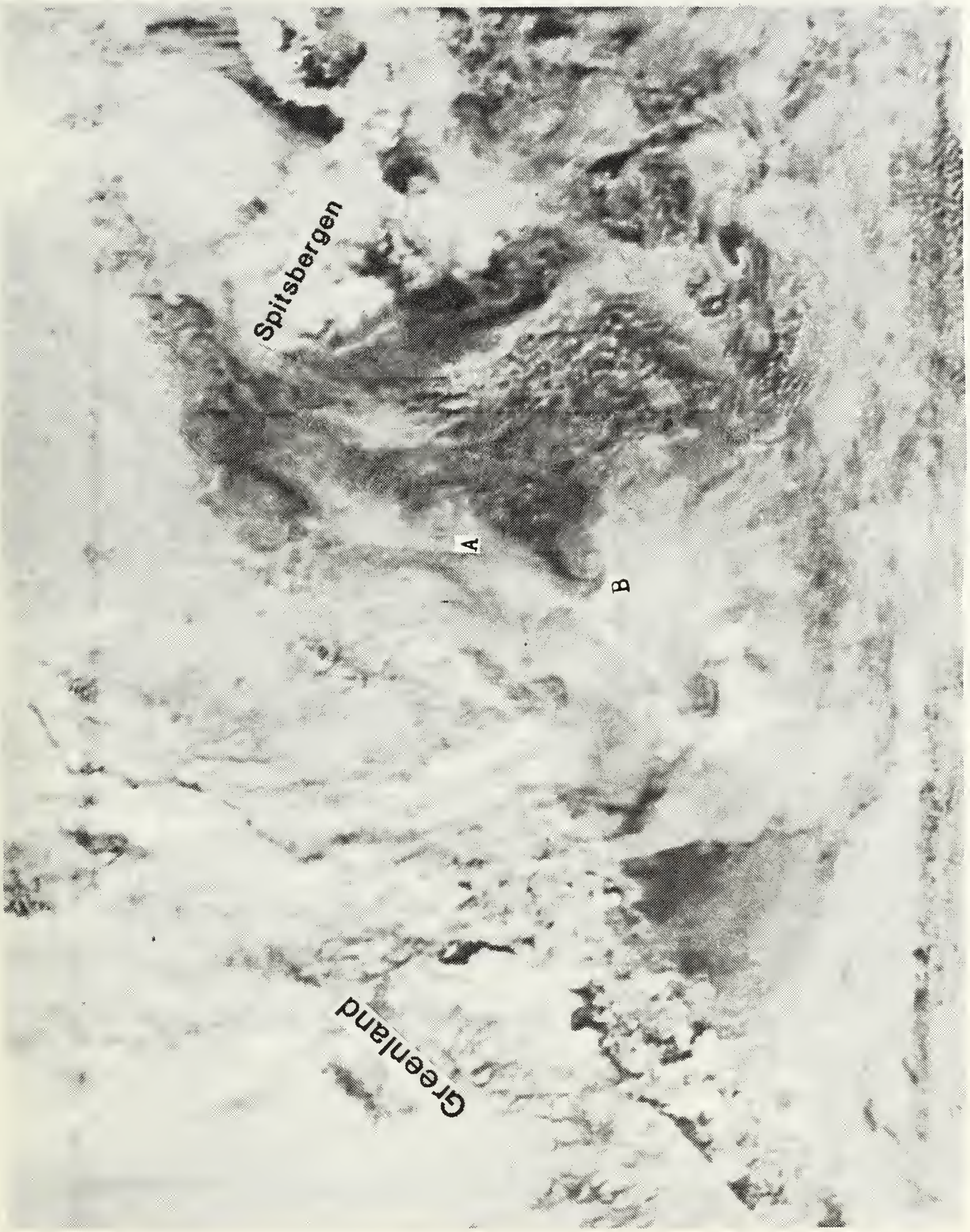


Fig. 17. Mesoscale Vorticies in the Fram Straits

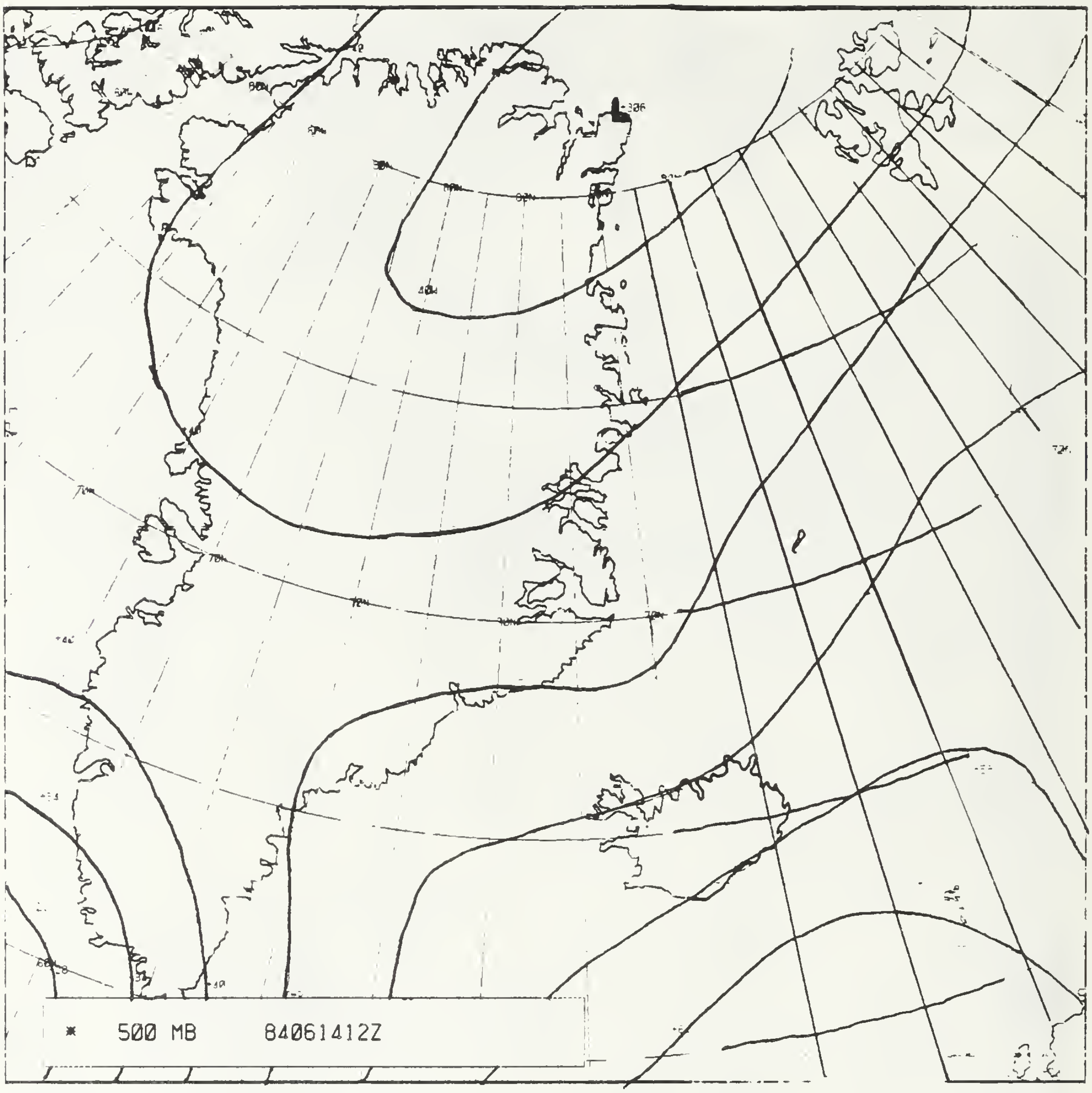


Fig. 18. 14 June 84 500 mb Analysis

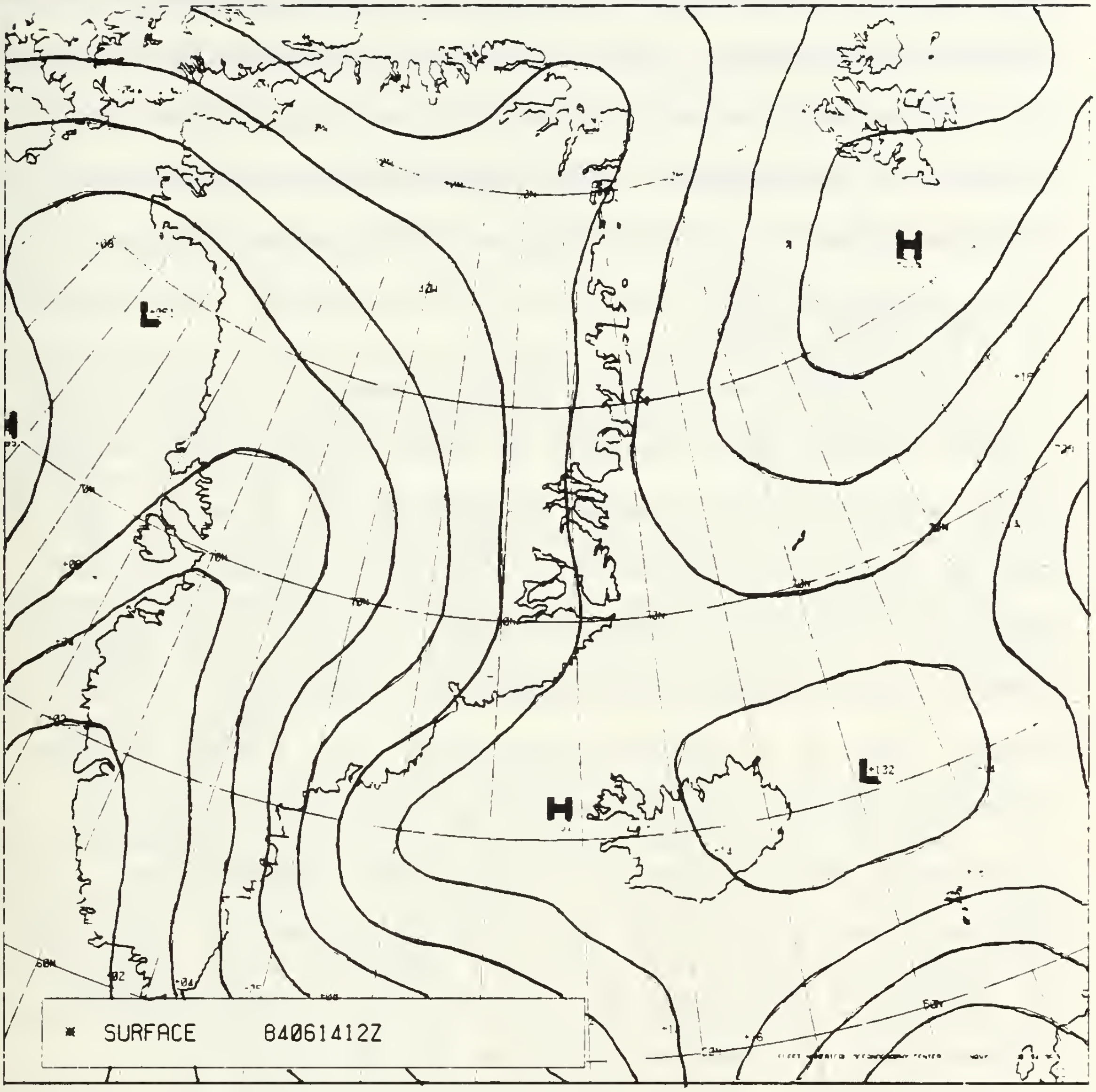


Fig. 19. 14 June 84 Surface Analysis

due to the tightening of the gradient then decreased as the gradient slackened. There is another maximum of wind speed on 12 June 84 in association with the occluded low which moved over Spitsbergen. High pressure decreased to a minimum about 12 June 84 then started rising again.

C. THE STORM PERIOD

This second period of the experiment, 11 June 84 to 1 July 84, was characterized by lower geopotential heights aloft which allowed storms to transit the straits. The SR charts, Figs. 7-10, show the difference in the long wave pattern. During the previous period, Fig. 7, an upper-level ridge extends over Iceland to Greenland. During this period, Fig. 9, a closed upper-level low is over northern Greenland with a trough extending southeast to Norway. The surface SR charts also show significant differences. During the previous period high pressure dominated the east coast of Greenland while during this period a trough extends from Norway into the southern portion of the straits.

The second period started with the entire area being dominated by high pressure on 15 June 84. A high was over Greenland (1016 mb) and ridging from the east. The jet started to intensify with a southwest-northeast orientation just south of Spitsbergen. On 16 June 84 the situation changed drastically. The surface high and the high pressure ridge receded northward to near the north pole. This allowed an occluded low tracking along the secondary storm track to break away from the polar front and move into the straits with a central pressure of 1008 mb. The jet was located east-west just south of the straits then turned abruptly over Spitsbergen north-south. The occluded low continued to drift north through the straits until it finally dissipated early on 18 June 84. The storm track is given in Fig. 20.

The time series from both ships, Figs. 13 and 14, show a dip in the pressure in association with the occluded low. The Hakon Mosby also reported a small maximum in wind speed of about 10 m/s.

On 18 June 84 a new upper-level low formed just north of Spitsbergen and the jet migrates northward to over Spitsbergen. The jet splits east-northeast of Iceland with one branch going east and the other headed north around the upper-level low. The next storm to affect the area had moved to the southeast coast of Greenland. The occluded low had a central pressure of 992 mb with a triple point low of 996 mb. The old occlusion quickly dissipated and the triple point low occluded and moved just south of the experiment area with a central pressure of 998 mb. The jet over Iceland abruptly moved north to just south of Spitsbergen. The occluded low was detectable at 500 mb with a weak low just south of the straits.

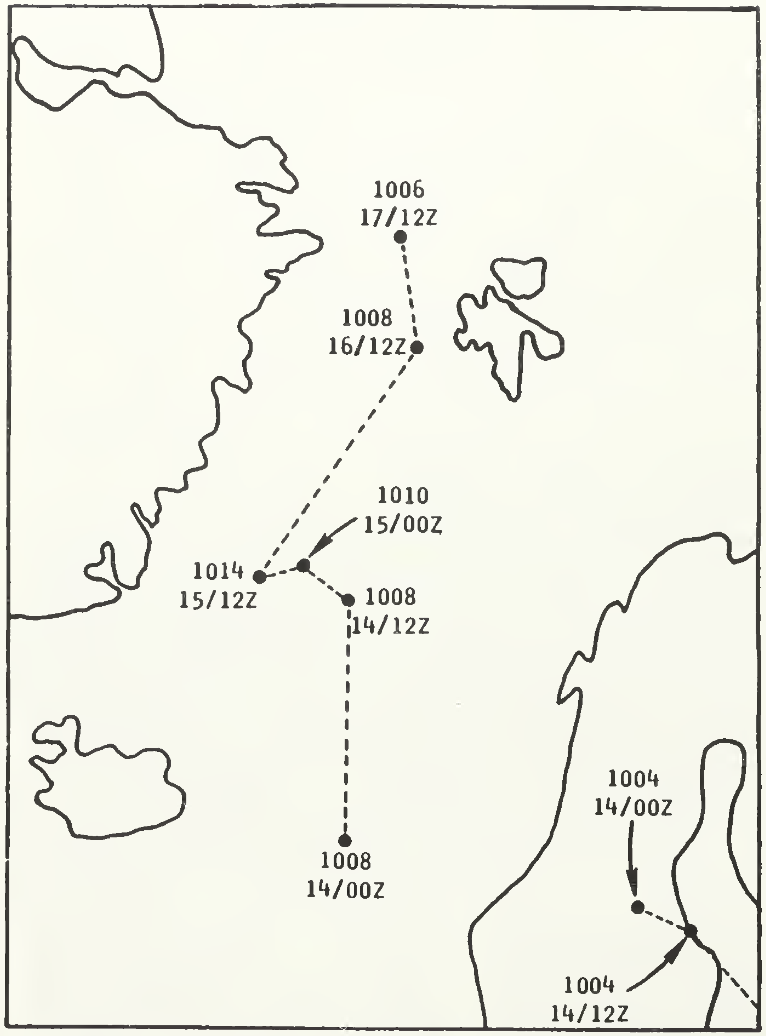


Fig. 20. Track of Storm Number 1

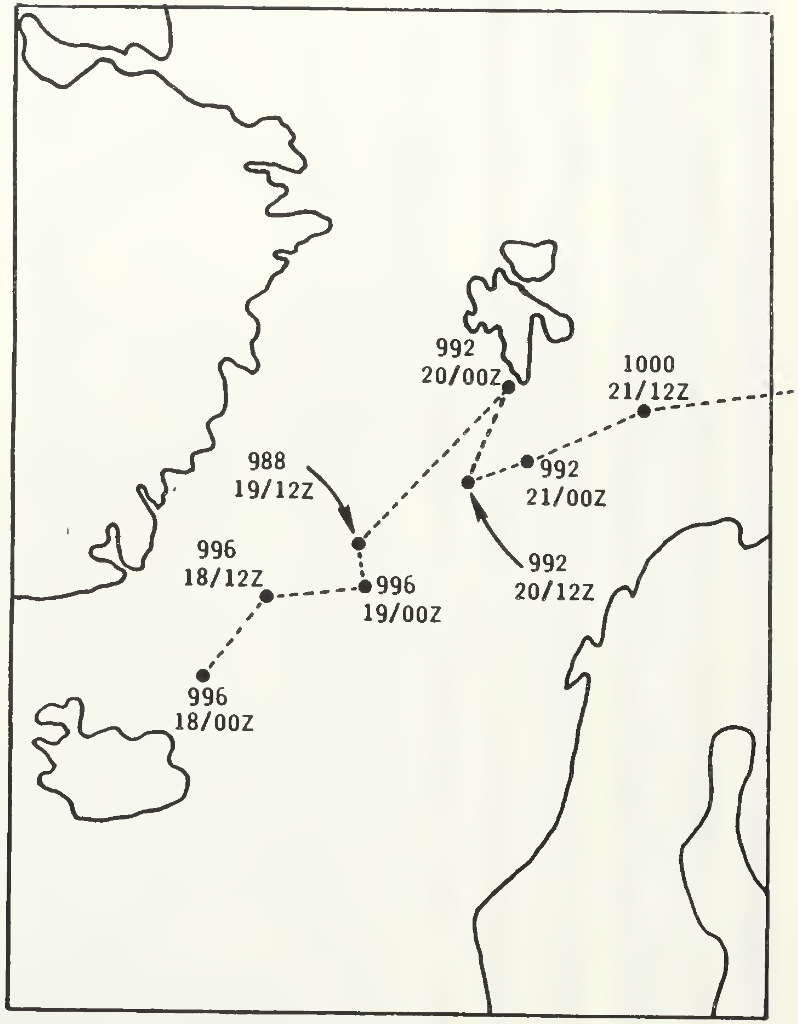


Fig. 21. Track of Storm Number 2

On 20 June 84 with the storm at 992 mb still just south of Spitsbergen the next storm was located on the northwest corner of Iceland with a central pressure of 1004 mb. The upper-level low associated with the exiting storm shrinks as the storm moves east. The storm leaves the area of the straits on 21 June 84. Its track is presented in Fig. 21.

Both ships' time series, Figs 13 and 14, show a minimum in pressure associated with the passage of the storm. The minimum was much more pronounced for the Hakon Mosby and the wind speed maximum was much higher near 15 m/s. The winds for the Polar Queen were only around 8 m/s at about the same time. A possible explanation is that the storm was filling and spreading as it moved north.

The next storm intensified to 992 mb. as it moved toward Norway on 21 June 84. A jet was present just south of Iceland. This situation persisted until 23 June 84. As the storm approached the Norwegian coast it stalled for about 24 hours and deepened to 988 mb before moving northwest through the straits. The circumpolar vortex moved down toward Canada and the jet moved to just east of Spitsbergen. The surface low slowed again in the vicinity of the ice edge on 24 and 25 June 84. It traveled north just on the cold air side of the jet over Spitsbergen. The low filled after leaving the Norwegian coast and was a 998 mb low over the ice edge. The storm filled to 1006 mb on the afternoon of 25 June 84 and left the ice edge. The jet drifted into the eastern straits. The occluded low deepened on 26 June 84 to 996 mb and subsequently moved northward to near the north pole. The track of the storm through the area is given in Fig. 22.

Shipboard observations, Figs 13 and 14, showed that this storm had the lowest pressure of the entire experiment. It also had the highest wind speed. The pressure curves for the two ships are of the same shape and depth. The wind speed extreme was recorded on the Hakon Mosby of 23 m/s. The Polar Queen experienced wind speeds of 14 m/s.

The fourth and last storm to directly affect the area began to move toward the area from Finland on 26 June 84. The storm had been stalled over Sweden for 72 hours before moving northward with a central pressure of 996 mb. The jet was showing some signs of splitting over the east coast of Greenland with one branch going north around the polar vortex and the other going southeast. By 27 June 84 the separation had increased as the storm moved off the Norwegian coast with a central pressure of 996 mb. The storm reached the southwest coast of Spitsbergen by 28 June 84 and dissipated there. This storm's track is given in Fig. 23. The 500 mb pattern is depicted in FNOC's 500 mb analysis, Fig. 24. NOAA-7 visual imagery for 24, 25 and 28 June 84 (not presented) show cloud lines formed by gravity waves produced as the wind blows over Spitsbergen.

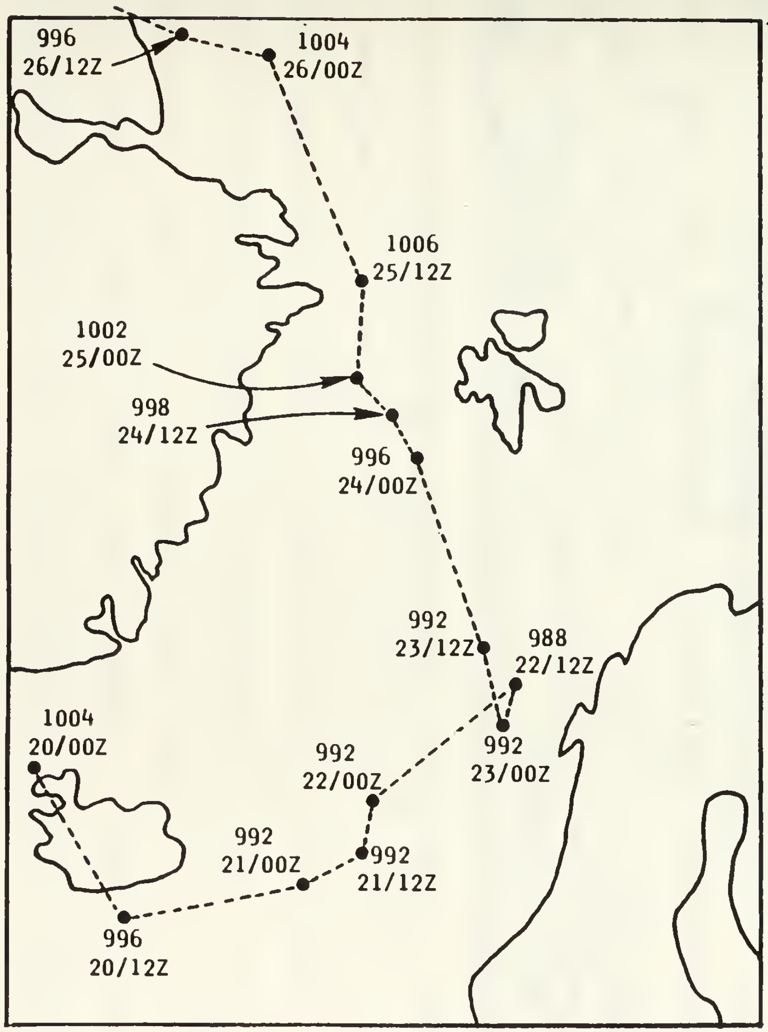


Fig. 22. Track of Storm Number 3

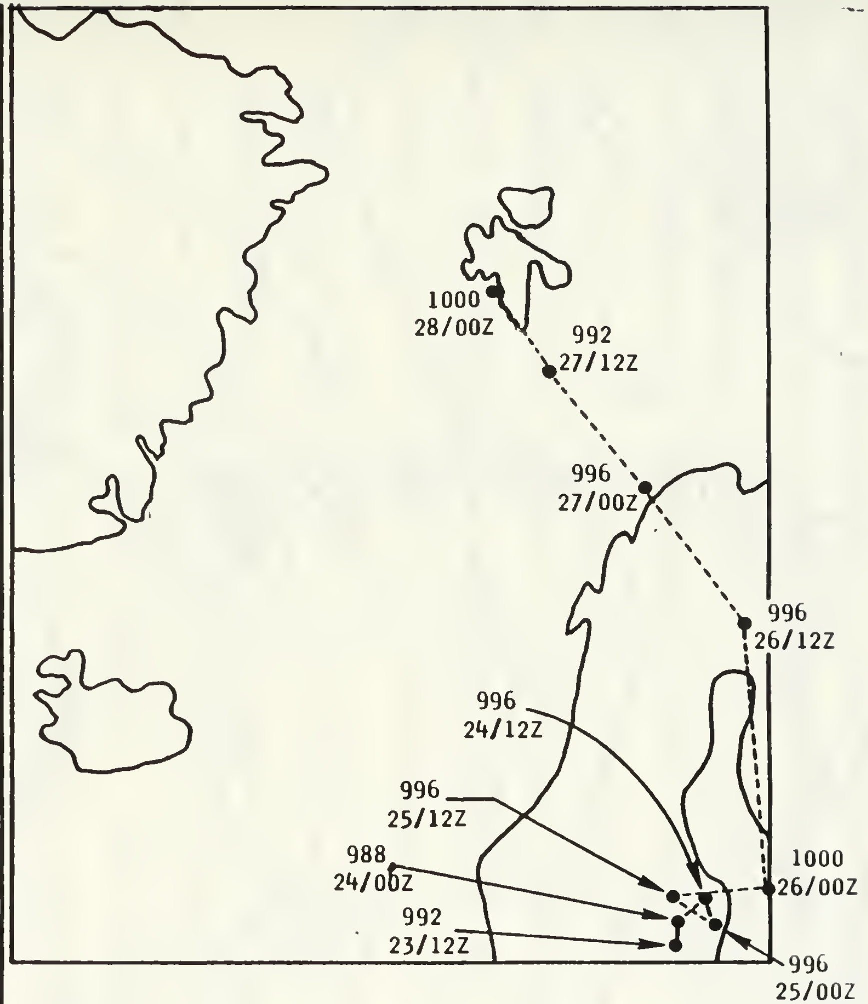


Fig. 23. Track of Storm Number 4

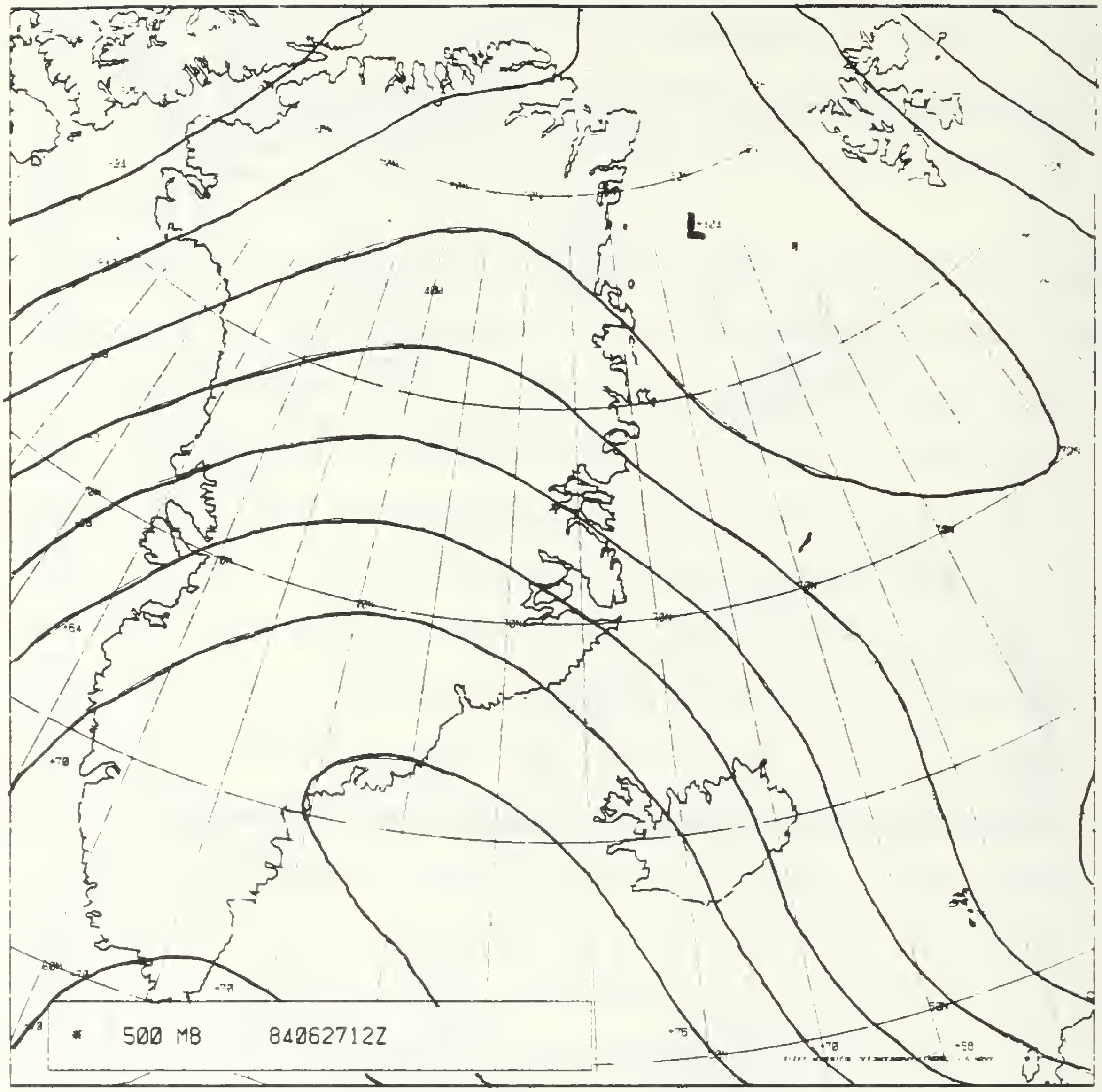


Fig. 24. 27 June 84 500 mb Analysis

Shipboard time series, Figs. 13 and 14, show a distinct dip in the pressure on 28 June 84. There was also another distinct wind maximum associated with this last storm. Both ships experienced about the same wind of 11 m/s.

The straits were in a col point starting on 29 June 84 and lasting for about 48 hours. Upper-level lows are located to the northwest and southeast and highs are to the southwest and northeast.

D. THE FINAL CALM PERIOD

During this final period of the experiment the area was again dominated by high pressure as shown in the SR charts representing the period, Figs. 10 and 11. This normal situation had returned by 30 June 84 and is shown by FNOC's 500 mb and surface analyses, Figs. 25 and 26. On the surface there was ridging along the east coast of Greenland and a weak trough over Spitsbergen. Aloft there was a weak jet over the straits. A lee trough formed off the east coast of Greenland in the afternoon but dissipated overnight. The high pressure built on 1 July 84 to 1022 mb and a ridge connected it to another 1026 mb high south of the straits. The upper-level ridge line was well defined in NOAA-7 visual imagery (not presented) by a north-south cloud line into the straits. A fairly strong lee trough forms with a 1012 mb low over the central coast of Greenland. This feature persisted for the day, drifting south along the coast and

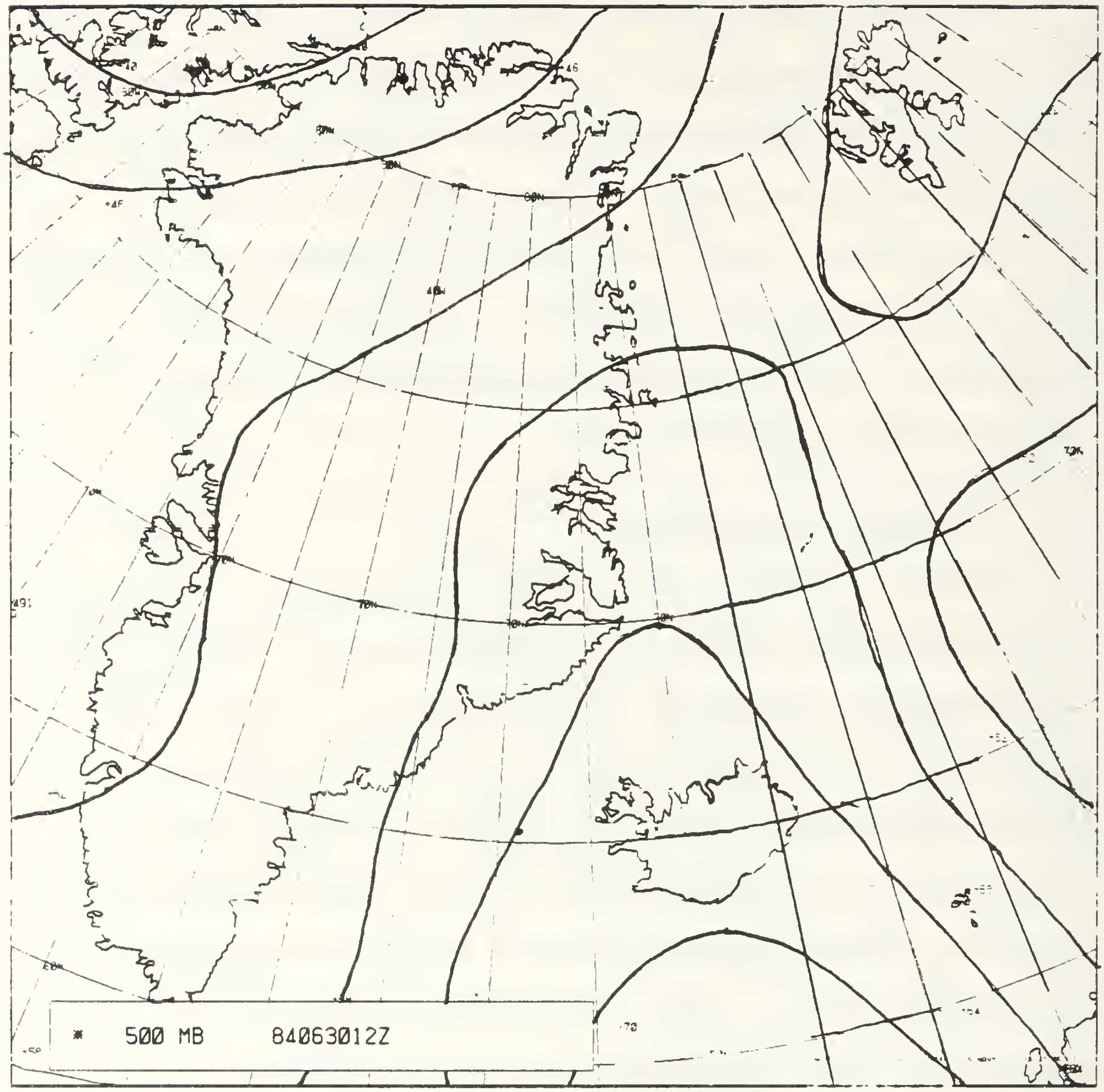


Fig. 25. 30 June 500 mb Analysis

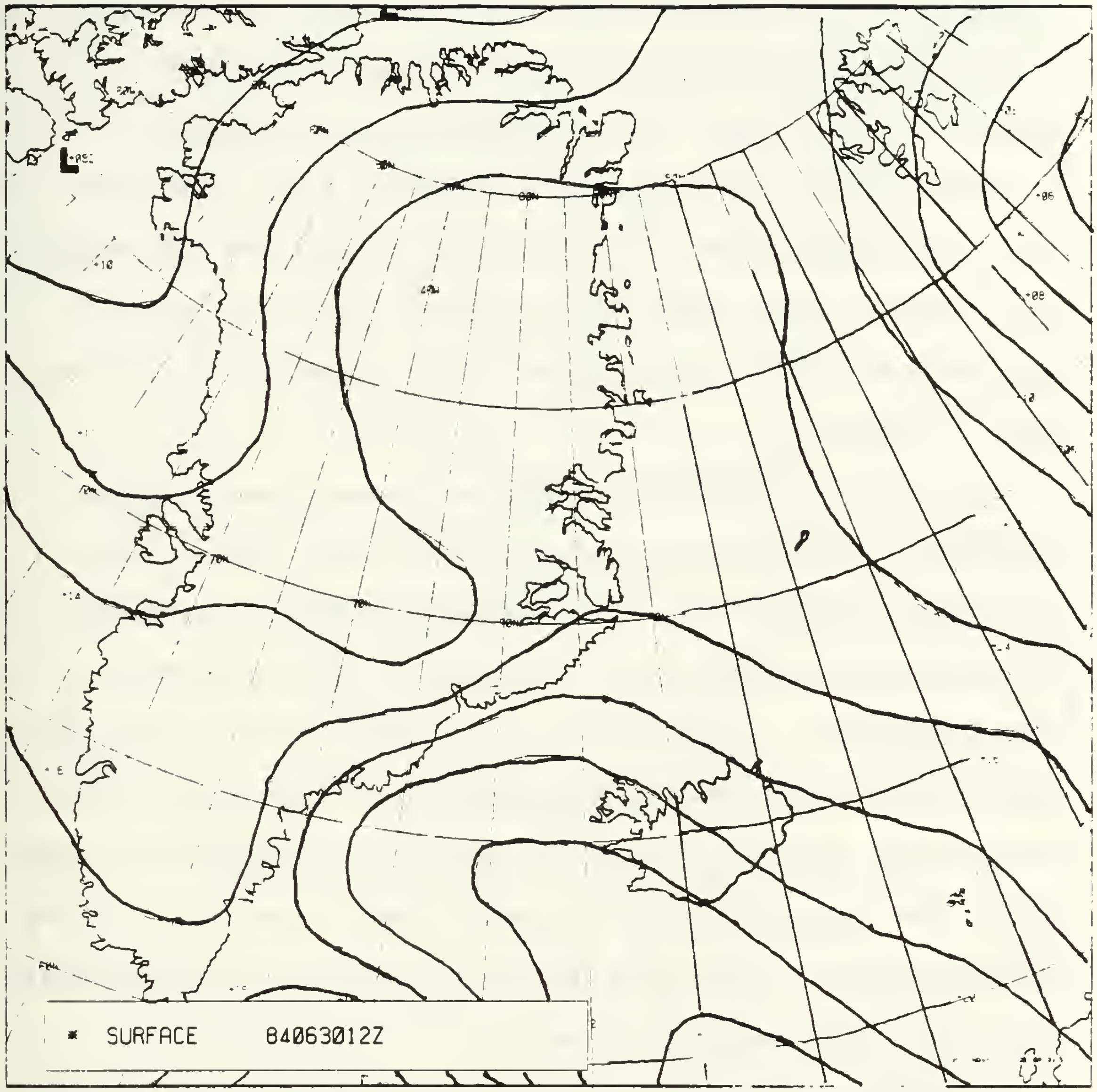


Fig. 26. 30 June 84 Surface Analysis

dissipating by the next day. The low appeared to have been topographically induced because it moved with the high terrain on its right and dissipated when it reached the end of the barrier. These surface features were associated with increased upper-level ridging which pushed the jet north of the straits. The upper-level vortex over Canada also receded toward the north pole. This situation continued until 5 July 84.

On 5 July 84 the high moved northward leaving the majority of Greenland with calm wind and a weak trough extended westward just south of Spitsbergen. FNOC's 500 mb and surface analyses for 5 July 84 are shown in Figs. 27 and 28. The polar vortex moved slightly toward the area and an upper-level low formed and moved directly over the area by the end of the day. Both the surface trough and the upper-level low deepened on 6 July 84. Near the end of the day the upper-level low began to drift eastward over Spitsbergen and the trough began to recede.

The time series, Figs. 13 and 14, show a flat pressure curve at about 1015 mb. The topographically induced low does not appear to have affected the pressure of the area but there was a wind speed maximum occurring at the time of the low.

On 7 July 84 a 1020 mb high returned to Greenland and a 992 mb occluded low moved north to just east of Spitsbergen. The upper-level low had continued to drift eastward

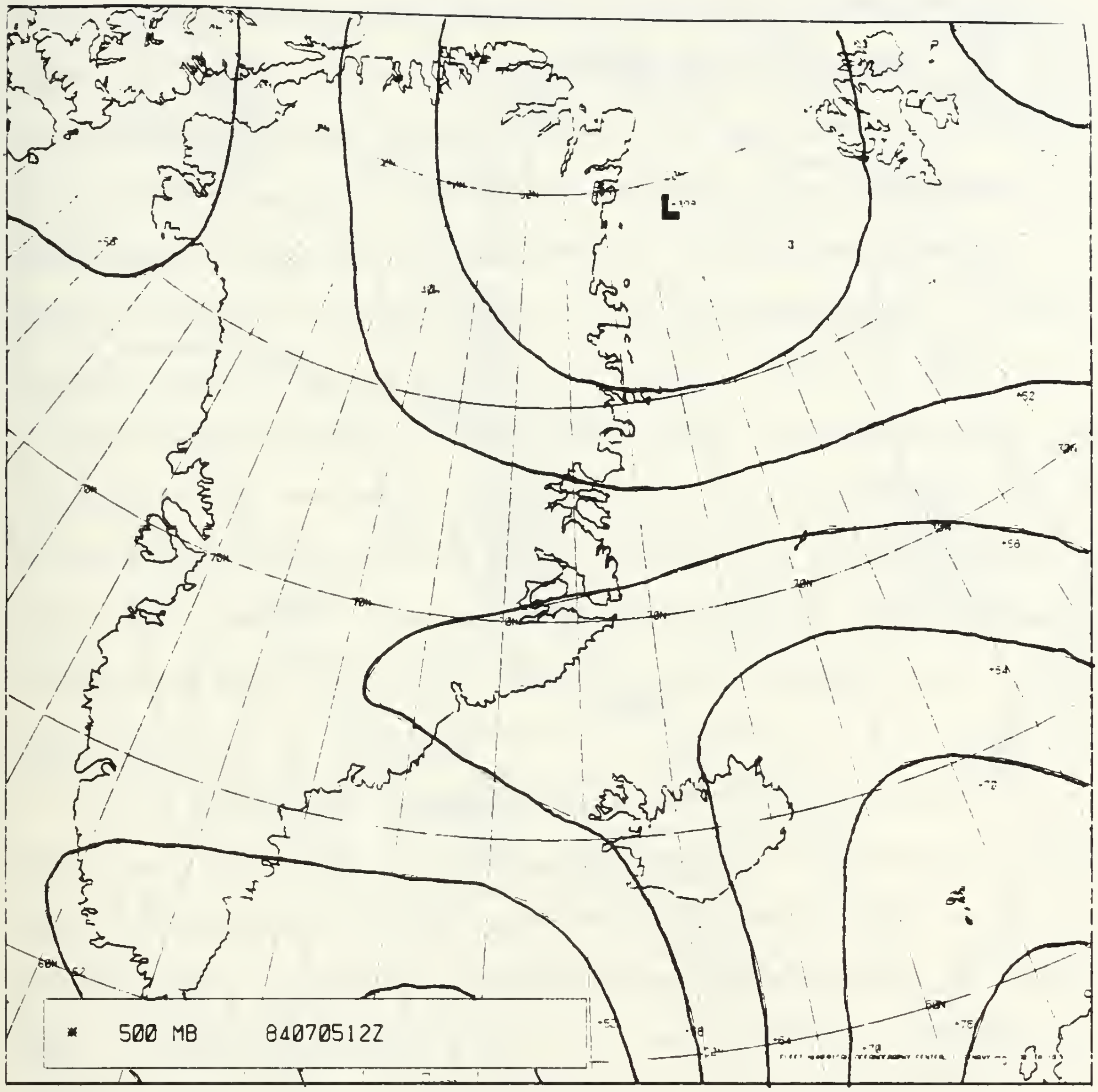


Fig. 27. 5 July 84 500 mb Analysis

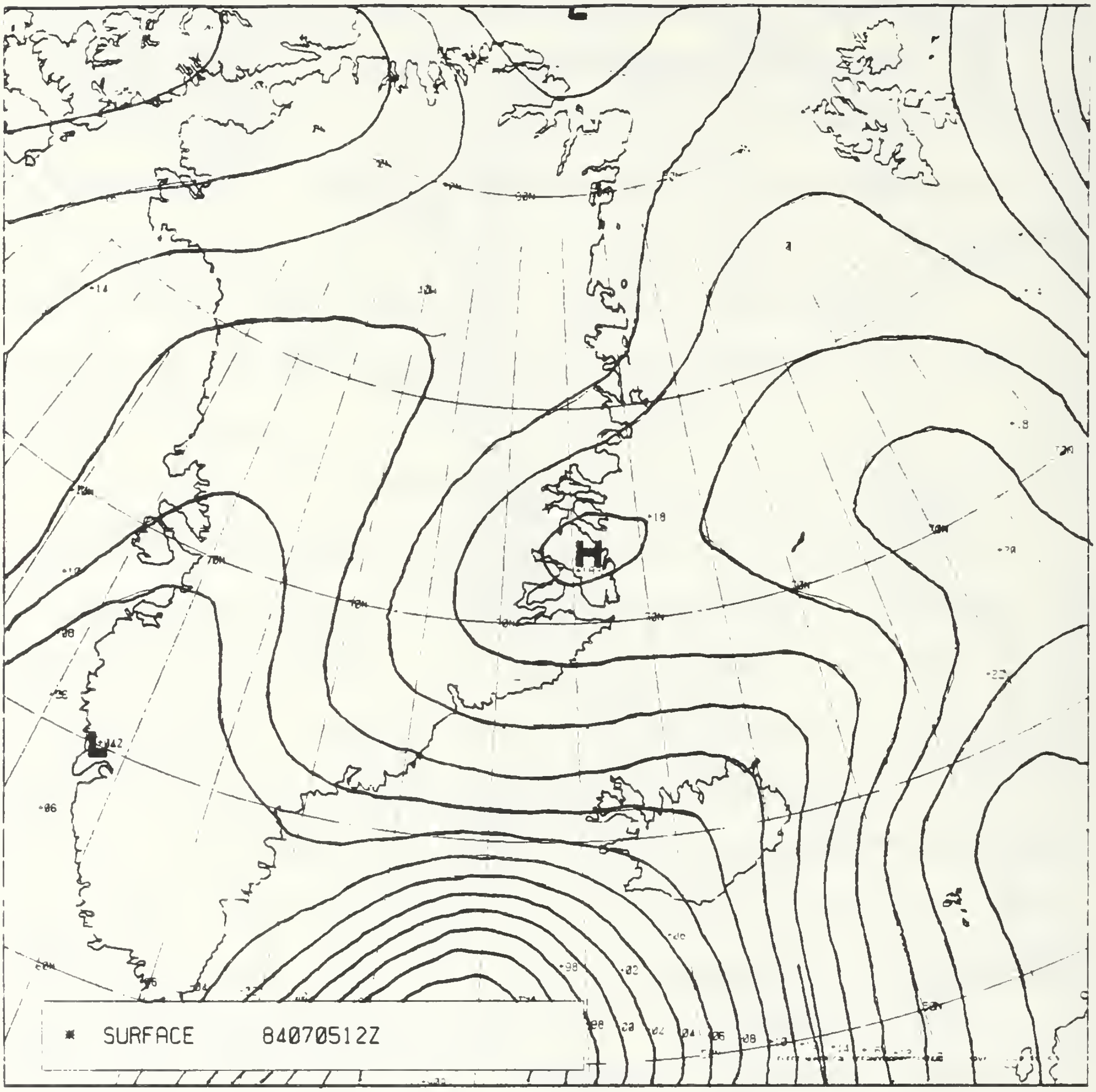


Fig. 28. 5 July 84 Surface Analysis

producing a north-south jet over the straits. The upper-level low began drifting north on 8 July 84 producing a more northwest-southeast orientation of the jet over the straits. The surface low had deepened to 980 mb producing a more northwest-southeast orientation of the jet over the straits. The surface low had deepened to 980 mb to the east of Spitsbergen tightening the gradient over the straits. The low filled to 990 mb and drifted north with the upper-level low producing more westerly winds in the straits. By 10 July 84 the jet had become almost zonal as shown by FNOC's 500mb analysis, Fig. 29. The surface low had moved almost to the north pole by 11 July 84 with a trough extending south along the lee coast of Greenland.

On 12 July 84 an upper-level ridge was again pushing into the area from the south and a 1012 mb high was centered over the Greenland landmass with a ridge extending east over the straits to another high well east of the area. A weak upper-level jet formed a "S" over the area with the bottom meander over Iceland and the top over Spitsbergen. This is depicted in Fig. 39. There was an occluded low over Iceland in association with this meander. The jet weakened late on 13 July 84 and the upper-level flow remained weak until the end of the experiment. The surface was dominated by high pressure for the rest of the experiment.

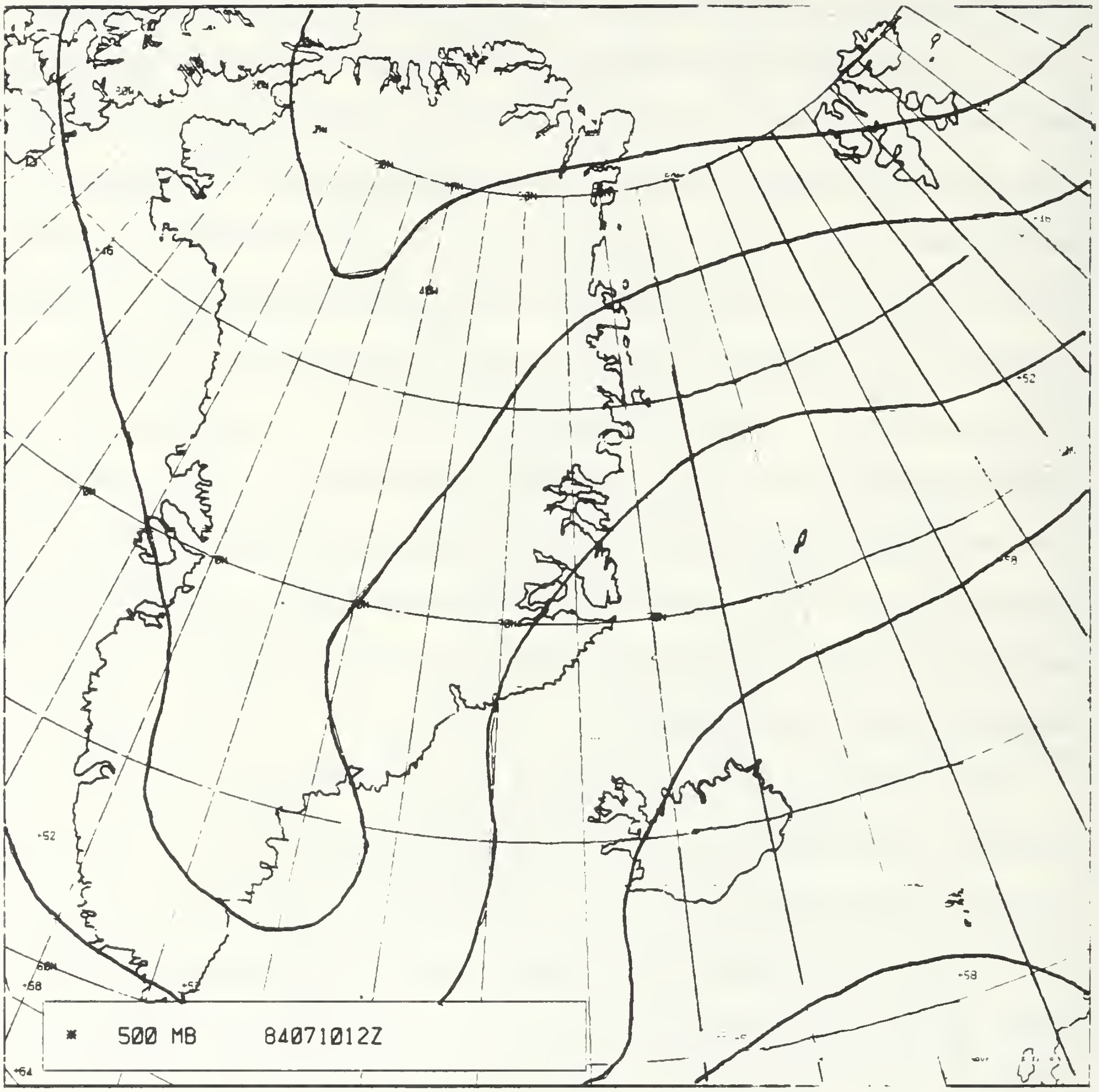


Fig. 29. 10 July 84 500 mb Analysis

The time series, Figs 13 and 14, show a dip in the pressure for the low passing on 8 July 84 with a corresponding increase in wind speed. Both ships experienced an initial increase in wind speed but the elevated winds persisted longer on the Hakon Mosby. Winds of over 10 m/s lasted until 11 July 84.

Synoptically MIZEX-84 was dominated by high pressure the majority of the time. From 11 June 84 to 1 July 84 an upper- level vortex dominated northern Greenland. This opened the straits to a series of four storms which transited through or very near the experiment area. During the rest of the experiment the storms transited to the south and east of the experiment area. Periods of high winds were experienced outside of the storm period due to a tightening of the pressure gradient as storms transited to the east of the straits. The events depicted on the NMC analyses correspond well with perturbations in the time series from the Polar Queen and Hakon Mosby.

IV. CASE STUDIES

A. GENERAL

In this section a thorough analysis of three cases will document the atmospheric conditions as they existed during a minor disturbance on 16 June 84, the major storm on 24 June 84, and an undisturbed situation from 12-13 July 84. These three cases were selected to contrast the meteorological conditions under different synoptic conditions. Surface analyses based on the surface observations of the ships involved, 500 mb analysis from the National Meteorological Center, (NMC), cross-sections and time series based on the soundings from the ships involved, satellite imagery from both NOAA-6 and DMSP F-6, and ice edge data gathered during the experiment will be used to compare and contrast the three time periods. The land based stations available on Greenland and Spitsbergen were not used for this reanalysis of the surface fields because of the effect of topography on their observations.

During MIZEX-84 a variety of meteorological data were collected from ship, aircraft, balloon and satellite. Surface observations and time series for the ships involved were taken from Lindsay (1985). The radiosonde soundings and DMSP imagery were obtained from the National Snow and

Ice Data Center in Boulder, Colorado. Surface and upper air analyses from NMC are used as an initial analysis to describe the events occurring in the area.

The Defense Meteorological Satellite Program (DMSP) satellite F6 was in a near-polar orbit during MIZEX-84. The resolution of the visual and of most of the infrared imagery is 0.5 km. The infrared mosaics have a resolution of 1.0 km (Fett, et al, 1977)

The NOAA-7 satellite was also in a near polar orbit and these images were obtained from Christian Michelsen Institute Bergen, Norway. The AVHRR images have a satellite subpoint resolution of 1.1 km. The image is taken with a scanning radiometer, with the resolution degrading away from the satellite subpoint.

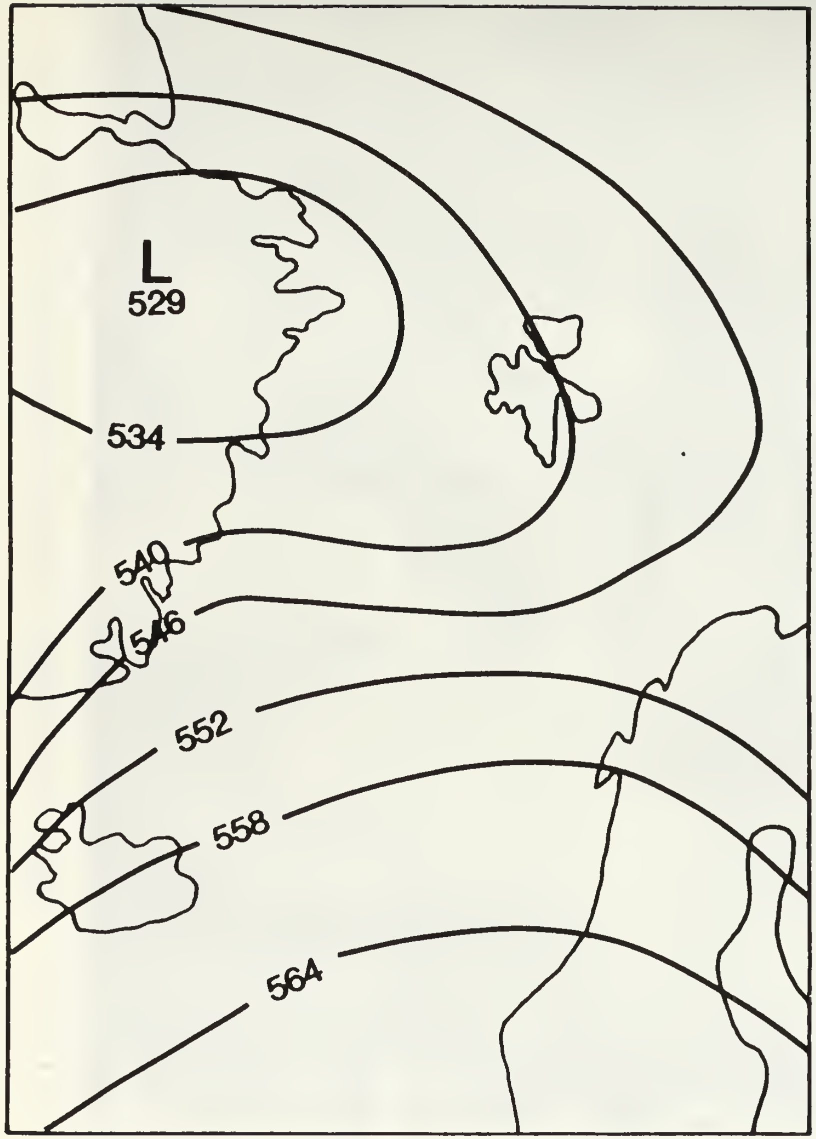
B. THE MINOR STORM OF 16 JUNE 1984

On 16 and 17 June 84 a weak storm, based on central pressure and wind speed, transited the straits and filled just on the ice side of the MIZ. Fig. 20 shows the track of the storm through the straits. This period was very early in the experiment and most of the ships were not on location yet. As a result additional data were not available to do an in-depth analysis of this storm. The synoptic situation can be used to contrast this storm which filled just north of the ice with the next case study of a storm which survived the transit of the ice. The surface analysis, ice edge position, and the position of the ships at 1200 GMT on 16 June 84 are given in Fig. 30b. The 500mb. analysis for 1200 GMT on 16 June 84 is Fig. 30a. The DMSP imagery is also available as Fig. 31.

There is a discrepancy between the NMC analysis and the DMSP imagery. The surface analysis shows a trough extending to the south which is confirmed on the DMSP imagery but there is also a trough extending to the northeast coast of Greenland. This may have been a double low system when it left the normal storm track with the second low on the Greenland coast in this picture. The storm analyzed by NMC is at letter "B" and the possible second low at letter "A".

The observations which were gathered from the Polar Queen showed approximately 18 hours of moderate snow under a stratus deck from 1000 GMT 15 June 84 to 0400 GMT on 16 June 84. Fog followed for the next 12 hours with visibilities as low as 1000 m.

There are three points to be emphasized. First, the central pressure of the storm as it left its parent system, as shown in Fig. 20, was only 1008 mb. With a central pressure this high, it was not an intense storm from the start. This low had already started to fill as it broke away from the triple point low which had formed. Second, the center of the upper-level low is over central Greenland. This position is too far west to be a reflection of the surface



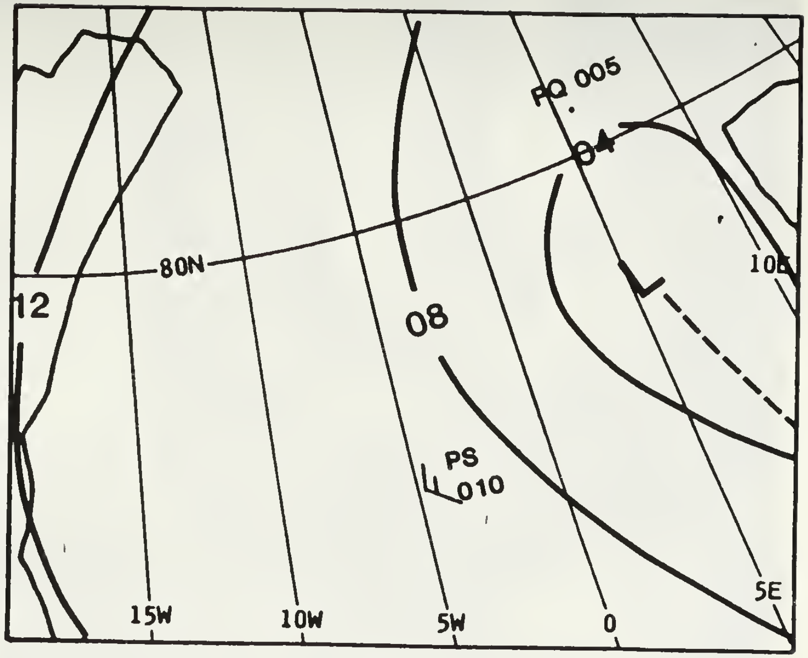


Fig. 30. (a) (Left) 500 mb Analysis for 0000 GMT on 16 June 84 (b) (Above) Surface Plot for 0000 GMT on 16 June 84

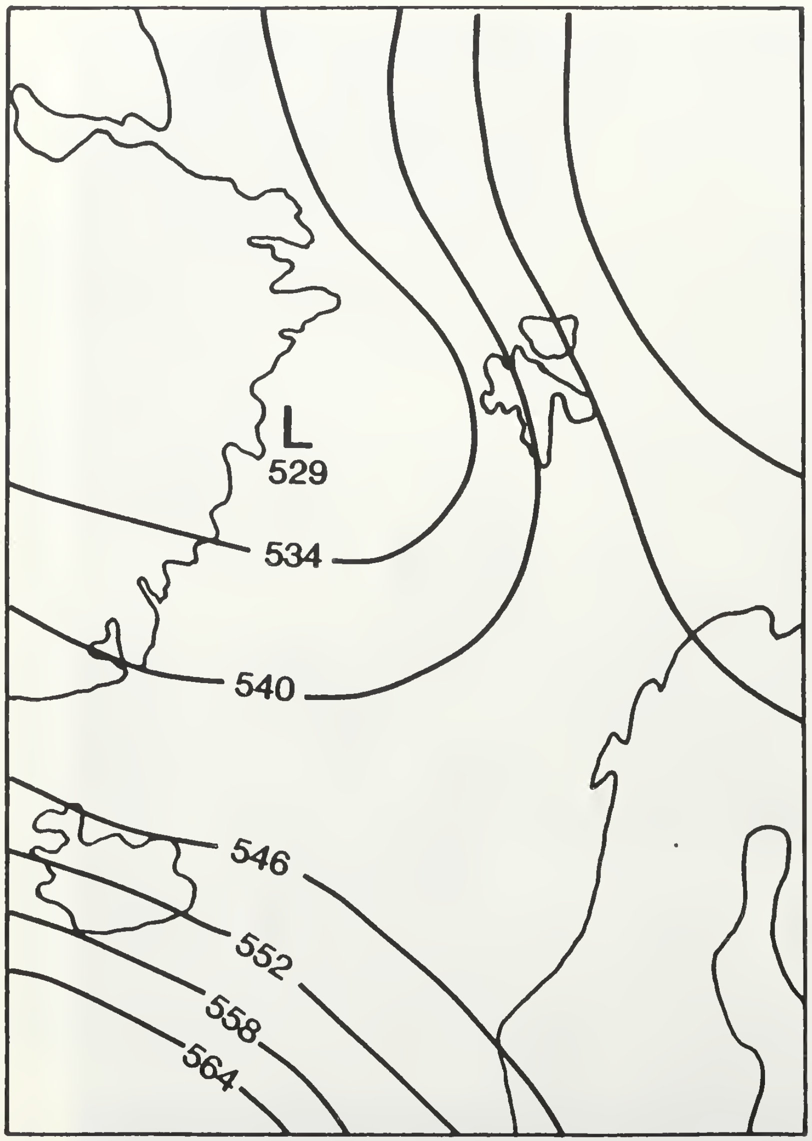
Fig. 31. DMSP IR Imagery for 0327 GMT on 16 June 84

low. And, finally, the jet over Spitsbergen is far too weak to adequately support any surface feature. This would seem to indicate that the upper air situation has the major role in destroying this low.

It should be noted that although the motion of the storm is dominated by the upper-level flow the speed is reduced by half as it transits the MIZ. A definite slowing can be observed between 1200Z on 14 June 84 and 1200Z on 15 June 84 as well as when the storm was in the experiment area. Fig. 6 shows that this first region of slowing corresponds with a different part of the MIZ. This may indicate that the MIZ slowed the storm.

C. THE MAJOR STORM OF 24 JUNE 1984

As a contrast to the first case, this is a storm which completed the transit of the MIZ and entered the polar basin. Fig. 22 shows the track of the storm as it transited the area. The track shows the storm slowing significantly on its trek northward as it crossed the MIZ. The storm was closest to the ships at 0000 GMT on 24 June 84. The surface analysis, ship positions and ice edge are given in Fig. 32b and the 500 mb analysis in Fig. 32a. The DMSP imagery, Fig. 33, shows the storm at "A". Other supporting analyses include the vertical cross-section nearly north-south from the Polar Queen to the Hakon Mosby for 0000 GMT on 24 June



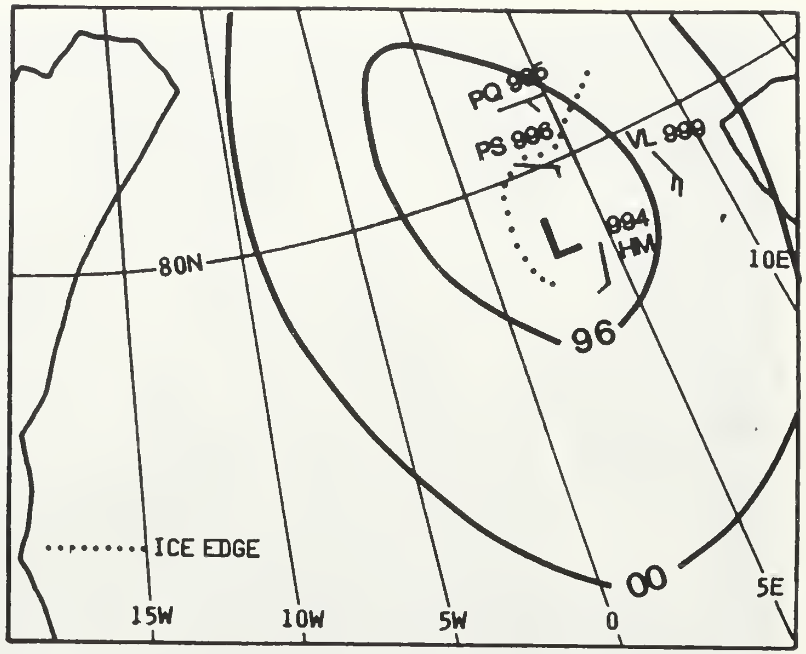


Fig. 32. (a) (Left) 500 mb Analysis for 0000 GMT on 24 June 84
(b) (Above) Surface Plot for 0000 GMT on 24 June 84

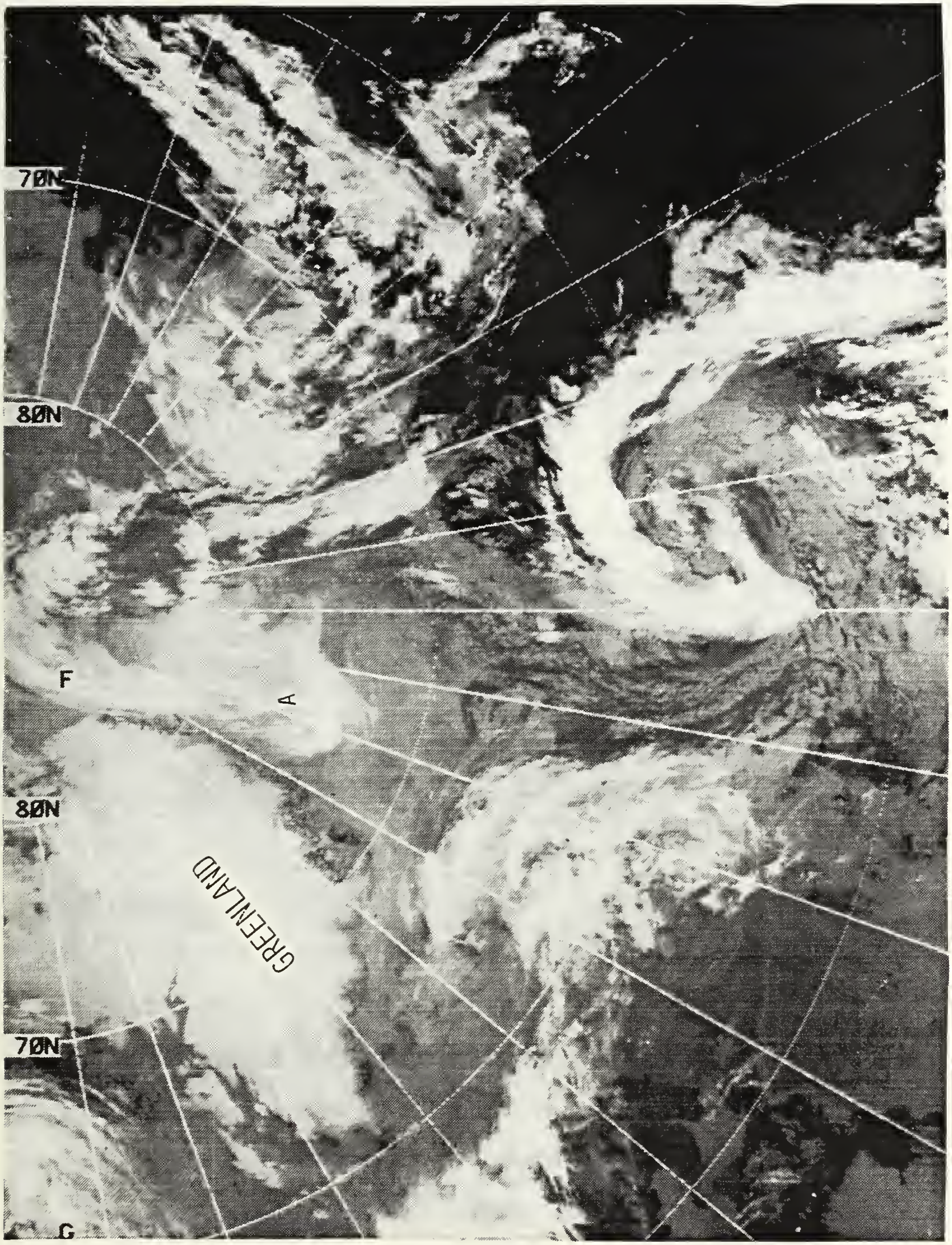


Fig. 33. DMSP IR Imagery for 1003 GMT on 24 June 84

84, a vertical time series for the Polar Queen, and a vertical time series for the Hakon Mosby, Figs. 34, 35 and 36.

The DMSP imagery, Fig. 33, in this case agrees very well with the reanalysis, Fig 32 a, which was done using the shipboard observations. The storm center, letter "A" on the figure, was well located by the NMC analysis (not shown). There is an obvious trough extending to the north.

The Polar Queen reported much less precipitation with the storm than the first case. There was moderate rain and snow mixed during the afternoon of 23 June 84. This was followed by fog with visibilities as low as 180 m until 0700 GMT on 24 June 84. The fog returned at 1800 GMT with light snow at 0600 GMT on 25 June 84. There was more moderate rain at 1200 GMT that day. The fog lifted at 1800 GMT.

The vertical cross-section and time series shown here are drawn to 650 mb. The isentropes above this level are fairly flat except for the expected variance due to the storm passage. Most of the thermal changes were in this layer. The storm can be identified in the vertical time series by its warm core. It passed the Hakon Mosby a few hours before 0000 GMT on 24 June 84 and the Polar Queen a few hours after 0000 GMT on 24 June 84. The warm core is shown by a cup shape in the isentropes. The warm air appears to be more compact as it passes the Hakon Mosby.

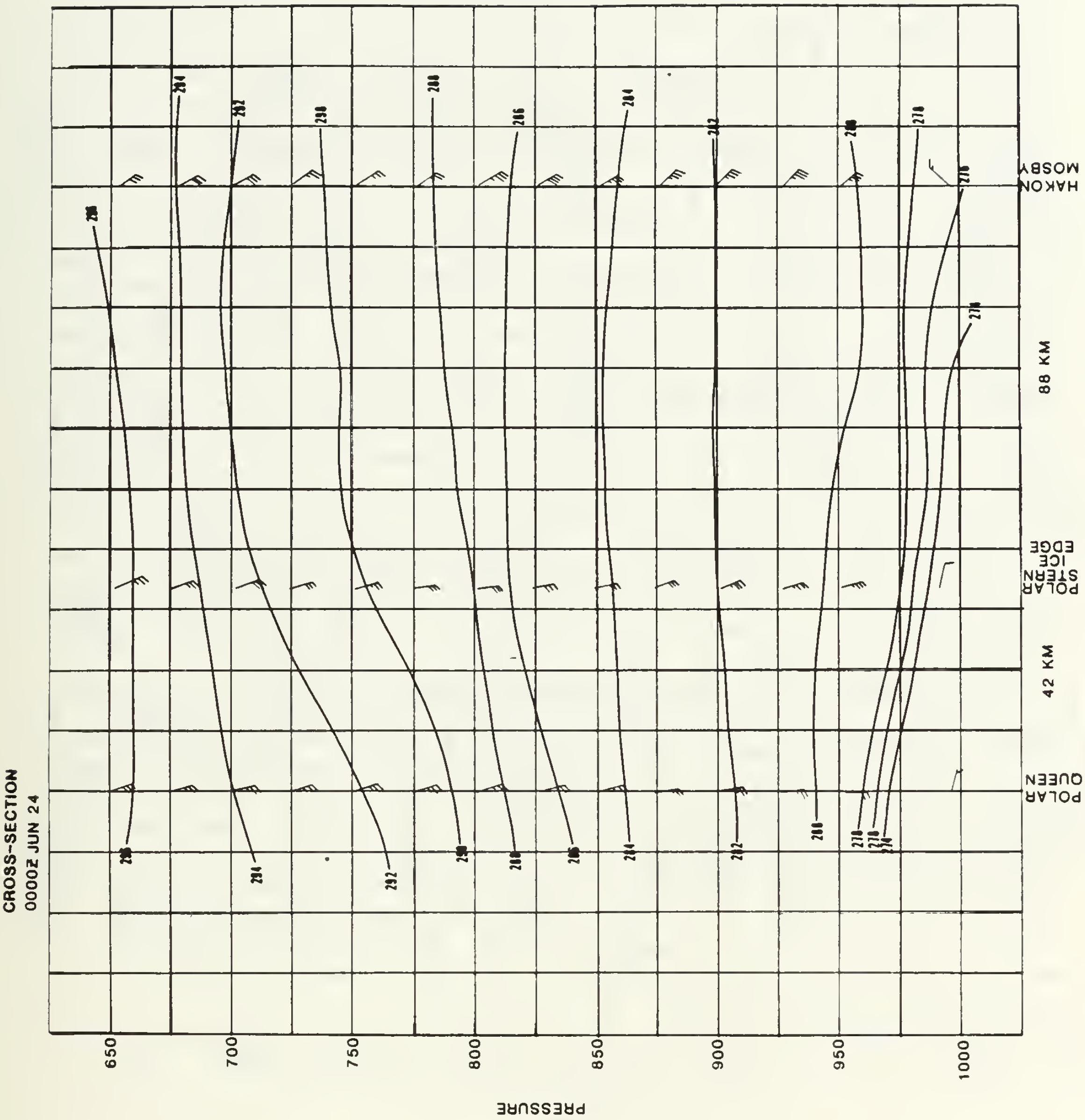


Fig. 34. Vertical Cross-section for 0000 GMT on 24 June 84

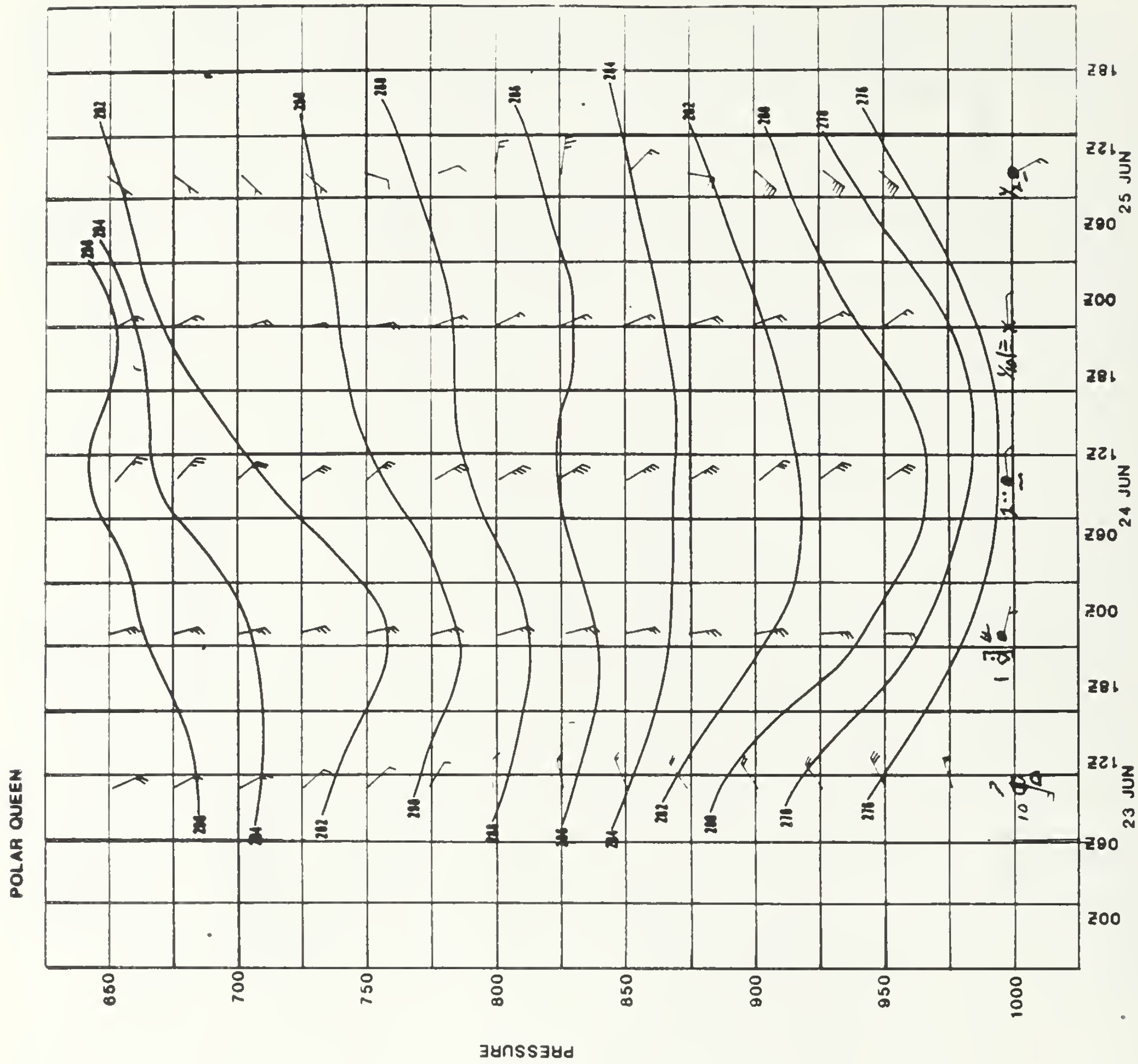


Fig. 35. Vertical Time Series for the Polar Queen

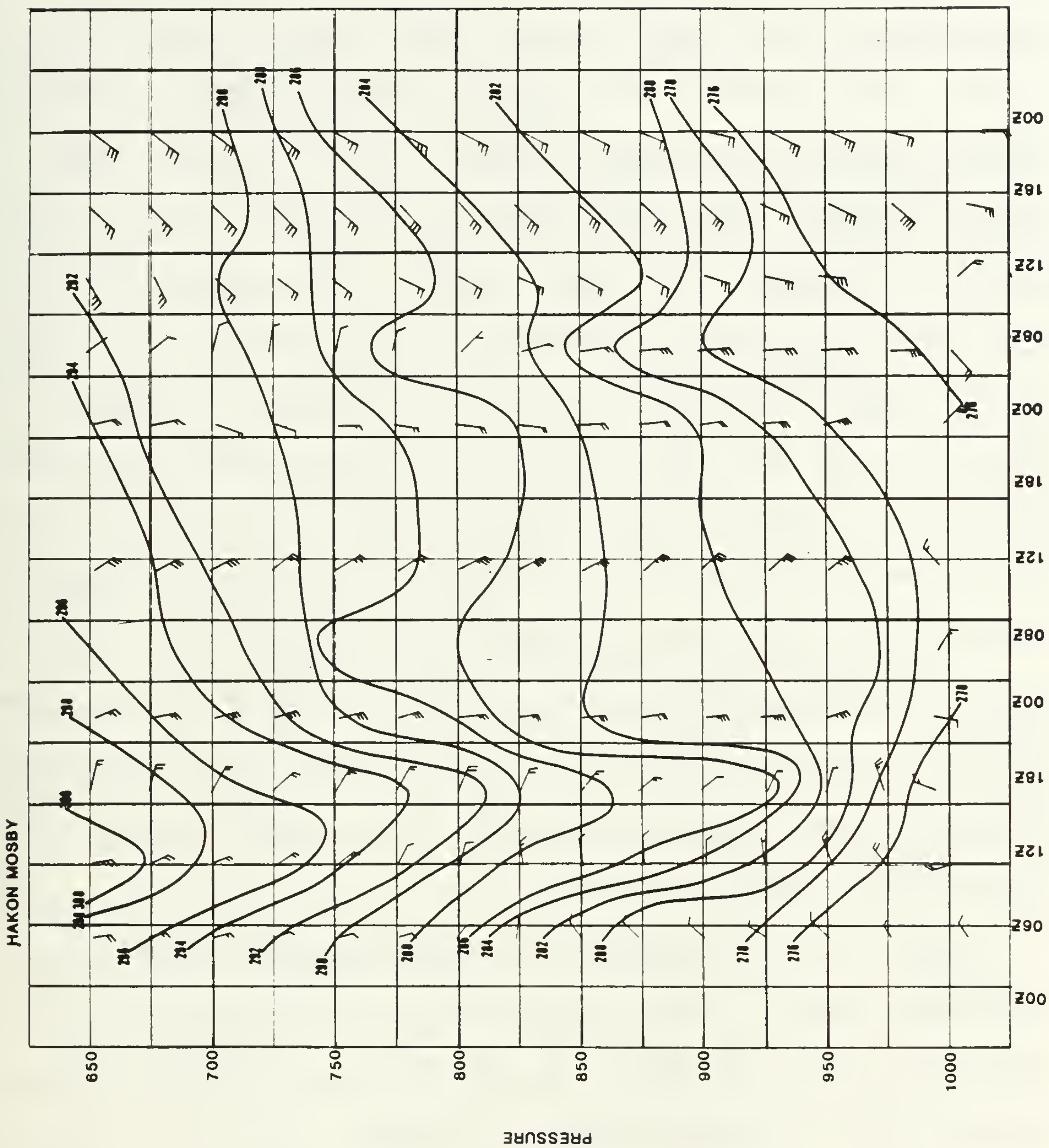


Fig. 36. Vertical Time Series for the Hakon Mosby

Below 925 mb the cup shape is more spread out similar to the shape of the storm as seen in the Polar Queen time series. The intense warm core is separated from a second weaker cup shape centered at about 800 mb by sharp temperature gradients. The isentropes do not slope as greatly in the time series for the Polar Queen. This may be because the storm is filling and spreading as it moves north. The storm's center is still well defined passing at about 1200 GMT on 24 June 84. The storm had already passed the Hakon Mosby at the time of the cross-section and lies between the Hakon Mosby and the Polar Stern in the area of the figure with no data. Warm air can still be observed below 950 mb and cold air centered at about 725 mb. A very stable layer of air just below 950 mb in the Polar Queen sounding slopes downward toward the center of the storm and no longer exists at the Hakon Mosby's station.

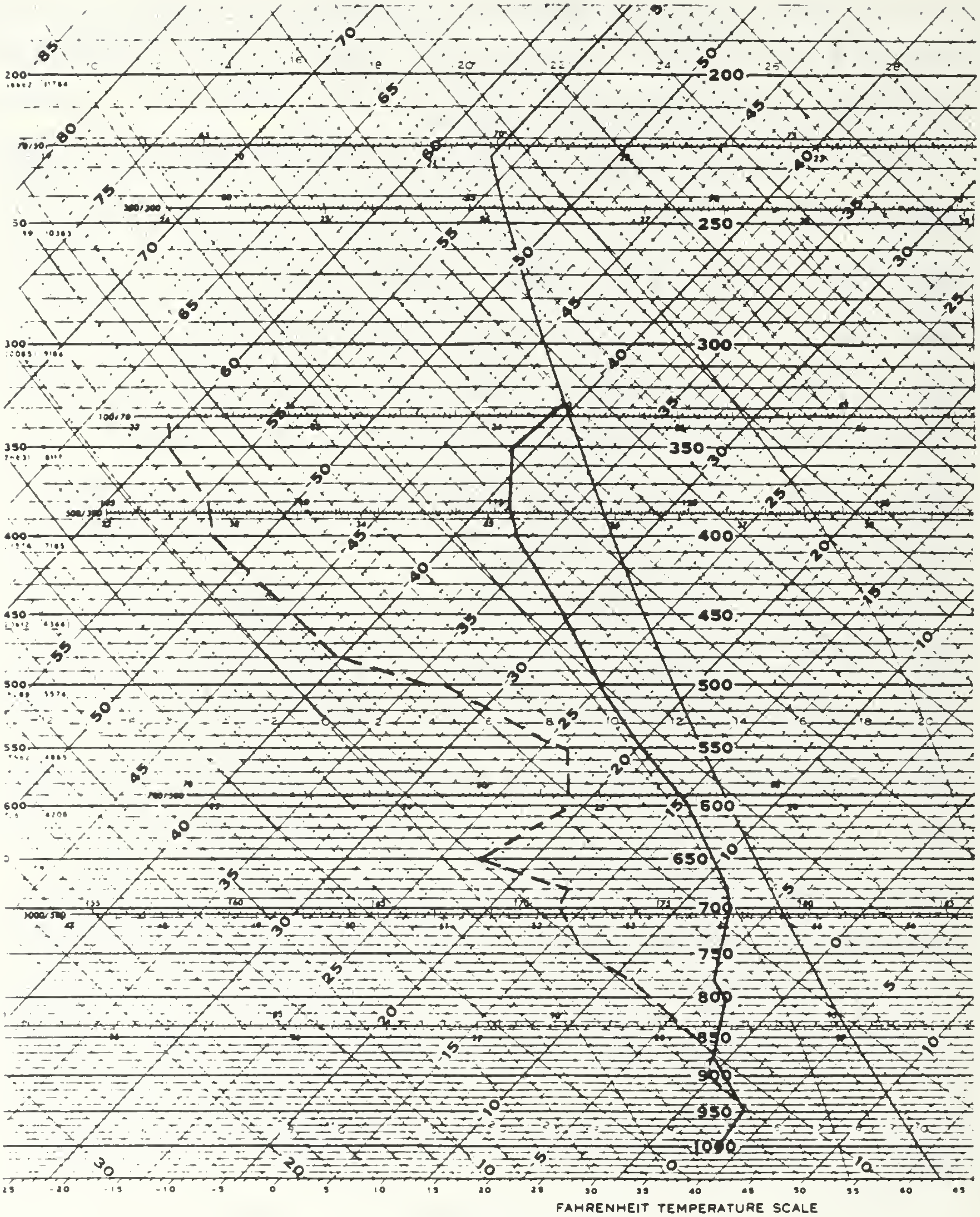
Shapiro (1985) showed an isentropic analysis of an Icelandic storm. A very weak area of warm air can be identified near the center of the cold air forming the cyclone. This feature seems to correlate with the warm core of this storm.

The plotted winds on the cross-sections and time series show a very slight wind maximum in some of the soundings. This maximum varies in height from just above the surface at 1000 GMT on 23 June 84 from the Polar Queen sounding to

825 mb from the Hakon Mosby at 1100 GMT on 24 June 84. When observed the maximum was normally only 2.5 to 5 m/s greater than the surrounding wind speeds.

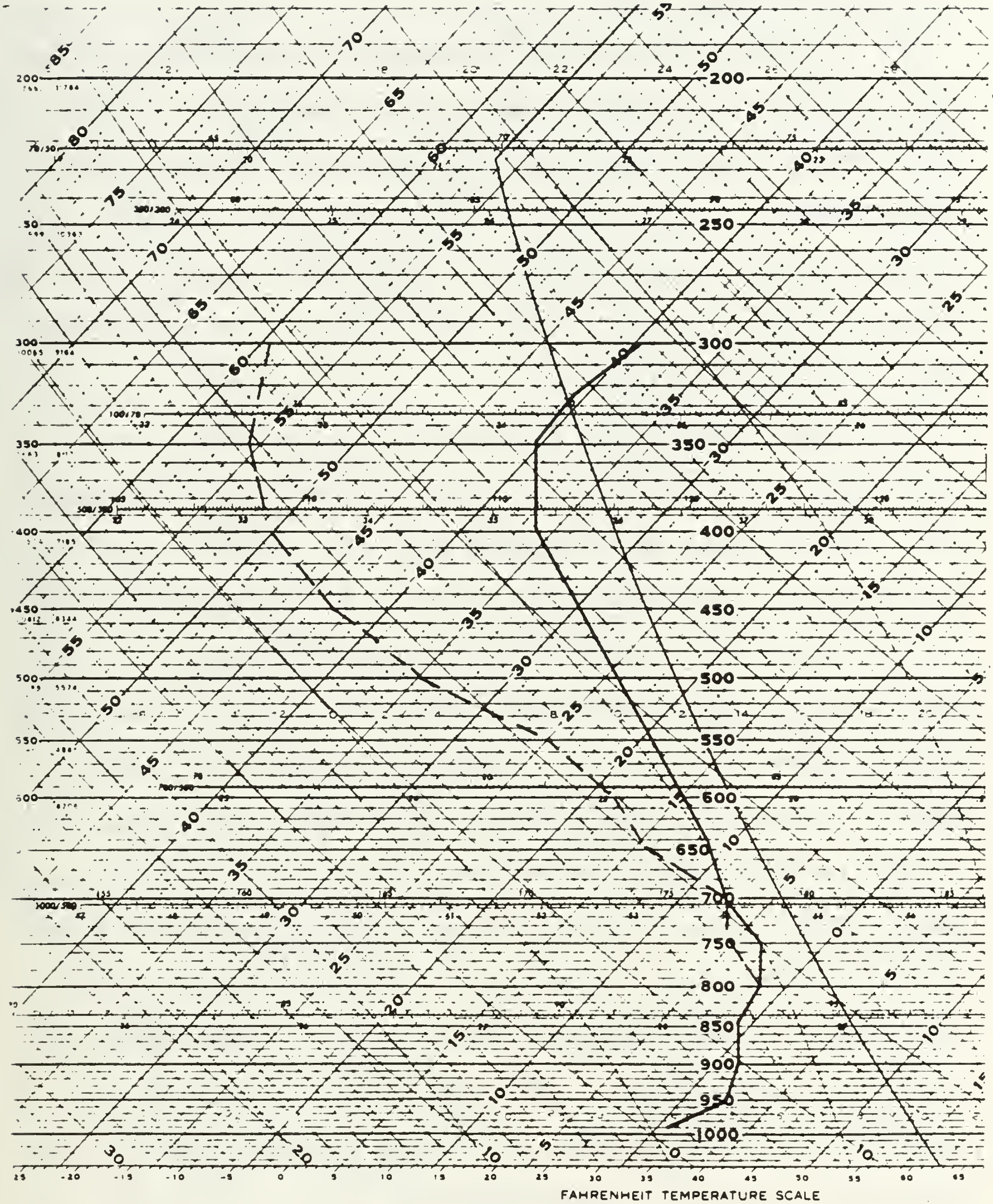
The soundings from the Hakon Mosby and the Polar Queen, Figs. 37 and 38, show a surface based inversion up to 950 mb then very stable up to 750mb. Above that point the sounding takes on a more standard slope. This corresponds well with the vertical time series. The air is also saturated up to 700 mb in the Polar Queen sounding and up to 870 mb for the Hakon Mosby. The tropopause at 350 mb is lower than the standard tropopause of 250mb.

This storm differed from the first one because it survived the transit of the MIZ. The movement of the storm indicated an affinity for the MIZ. This was shown by the storm slowing while over the MIZ. The storm also deepened about 12 hours after it left the MIZ. The storm was significantly more intense than the first storm. The central pressure was 992 mb when it left the climatological storm track. The lower central pressure combined with a stronger jet and closed low aloft allowed the storm to survive for an extended period of time after it had entered the polar basin.



Hakon Mosby	
NUMBER	STATION
2258	23 June 84
TIME (GCT)	DATE (GCT)

Fig. 37. Sounding From the Hakon Mosby



Polar Queen
NUMBER STATION

2300 23 June 84
TIME (GCT) DATE (GCT)

Fig. 38. Sounding From the Polar Queen

D. AN UNDISTURBED CASE

As a further contrast of atmospheric conditions in the MIZ a relatively quiescent period was chosen for the last case. The surface analysis, ship position and ice edge position for 1700 GMT on 12 July 84 are shown in Fig. 39b. The NMC 500mb analysis for 1200 GMT on that day is Fig. 39a. The DMSP imagery shown as Fig. 40. The surface winds were very light with on ice flow.

The upper-level flow is easy to distinguish from the DMSP imagery. A thin band of high clouds extends from the east central coast of Greenland over the southern portion of the straits. This cloud band marks the northern meander of the "S" described on page 58 in the previous section. From Greenland the cloud band then thickens and curves along the coast and back out to sea. Surface features are hard to identify because of the lack of temperature contrast.

The vertical time series and cross-section, Figs. 41, 42 and 43, show a small perturbation in the temperature field moving through late in the day on 12 July 84. The Hakon Mosby experienced a shift in wind direction just above the surface at approximately 1600 GMT. This wind shift was associated with the passage of a weak perturbation in the isentropes centered at about 850 mb. The surface wind which had been variable up to this time became southerly after the passage. A similar perturbation in the temperature field was observed in the Polar Queen vertical time series with

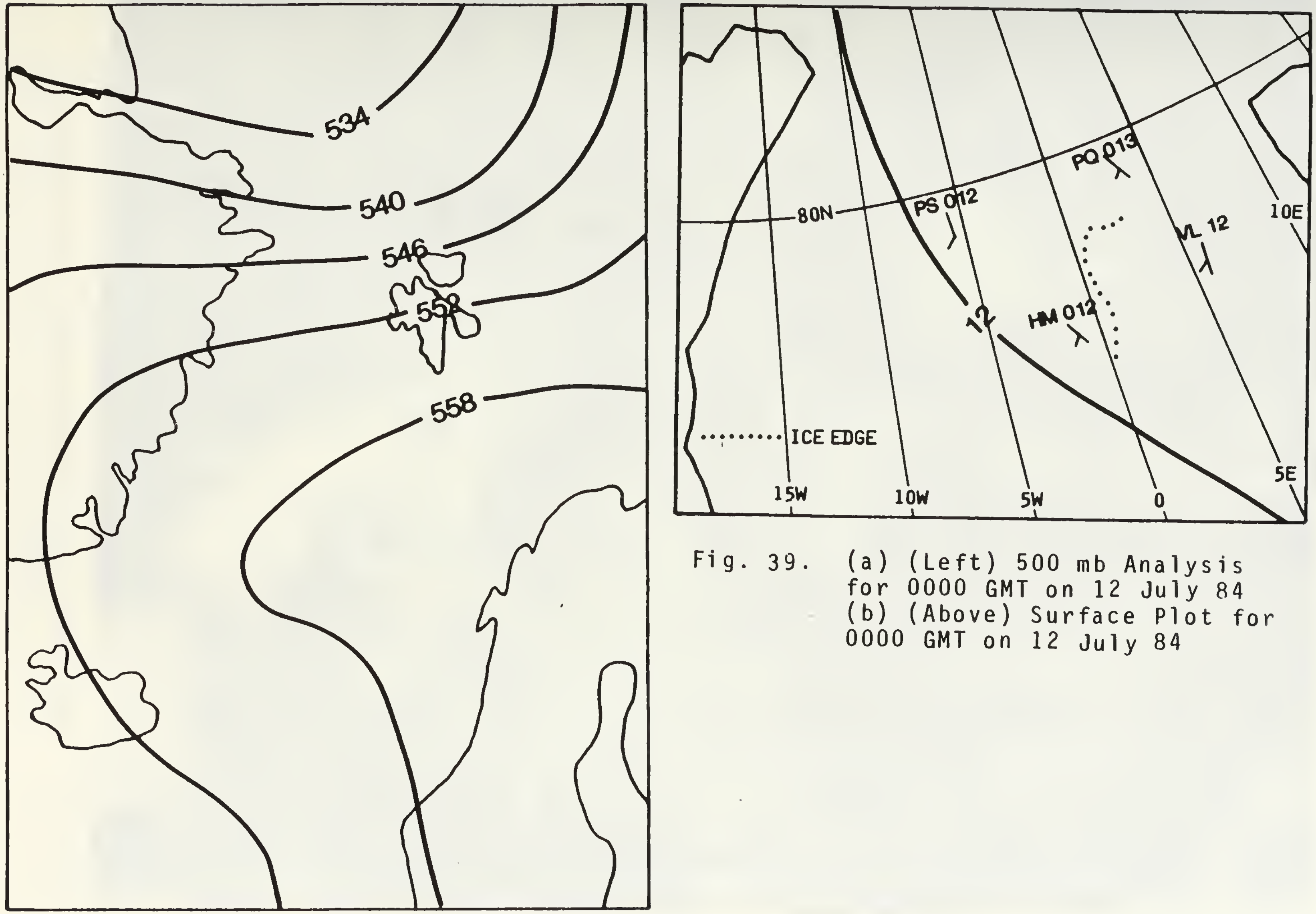


Fig. 39. (a) (Left) 500 mb Analysis for 0000 GMT on 12 July 84
(b) (Above) Surface Plot for 0000 GMT on 12 July 84

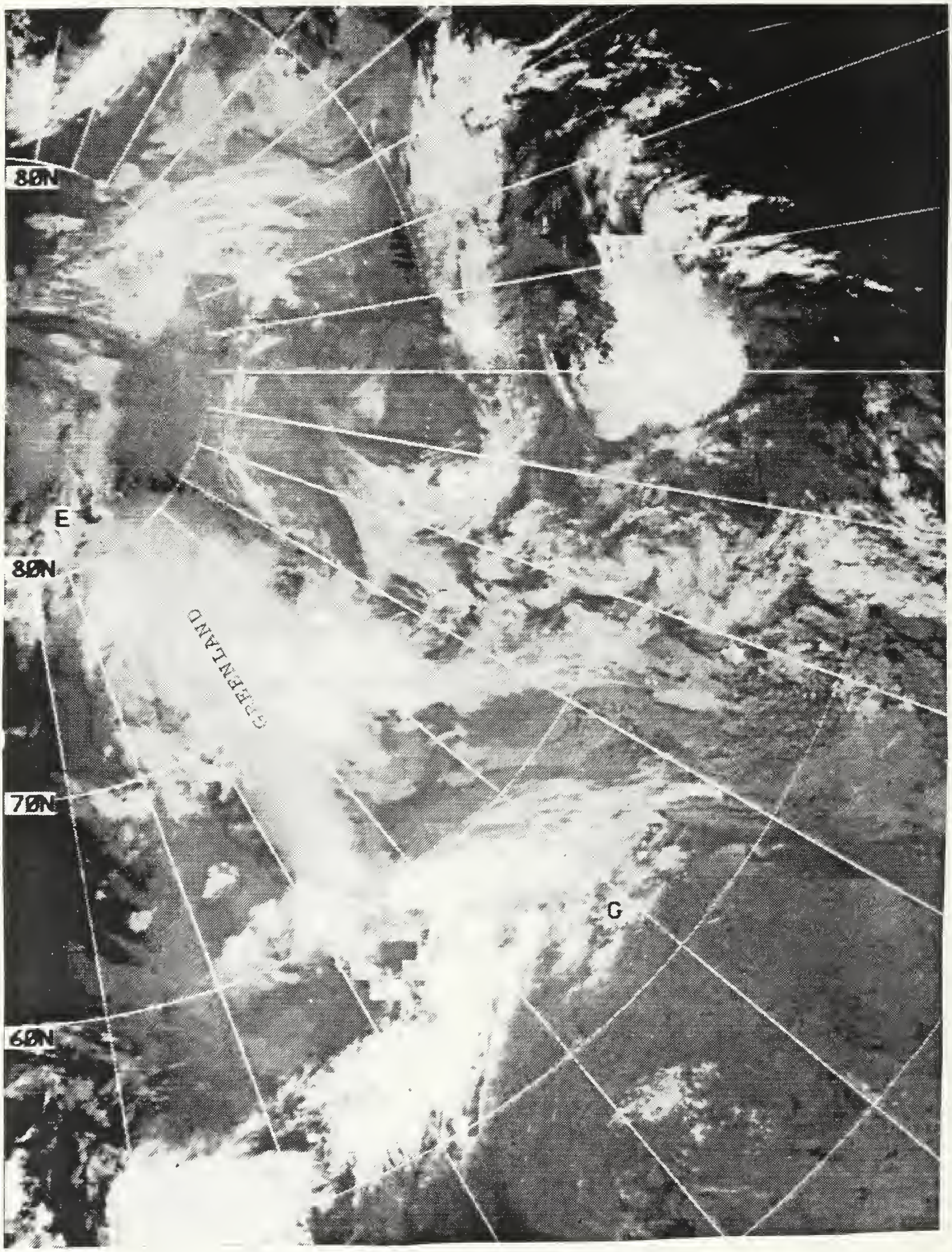


Fig. 40. DMSP IR Imagery for 0802 GMT on 12 July 84

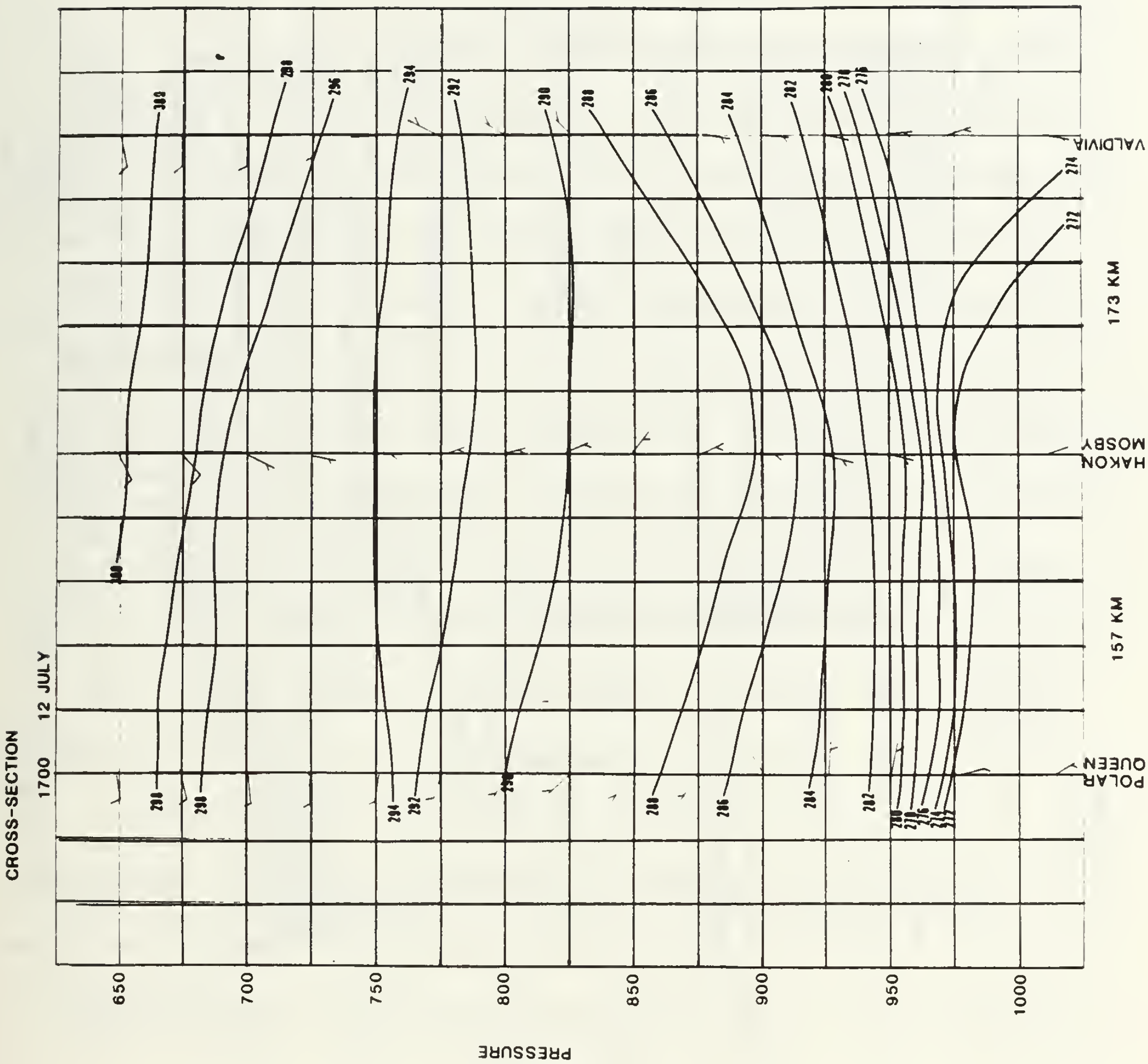


Fig. 41. Vertical Cross-section for 1700 GMT on 12 July 84

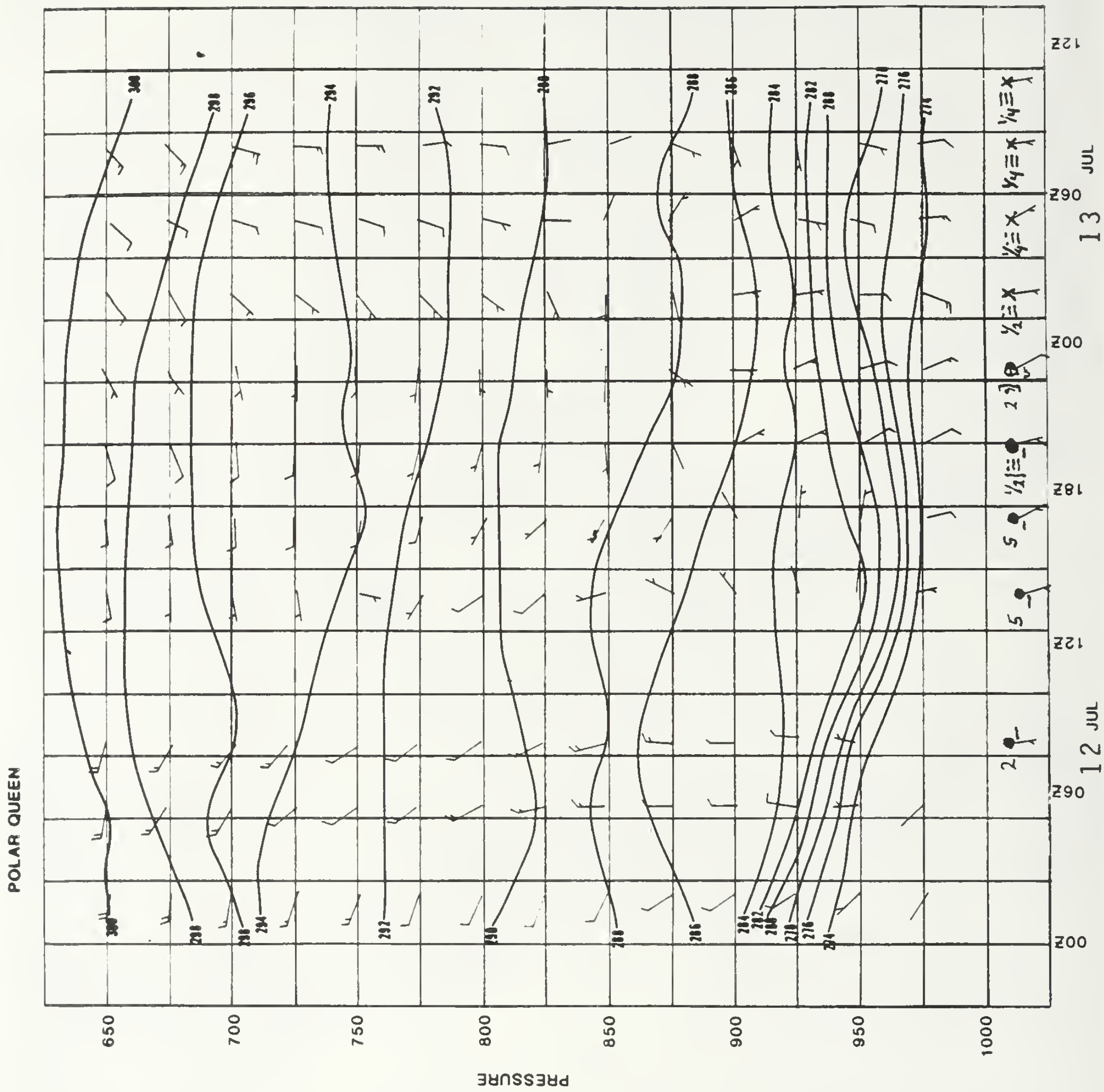


Fig. 42. Vertical Time Series for the Polar Queen

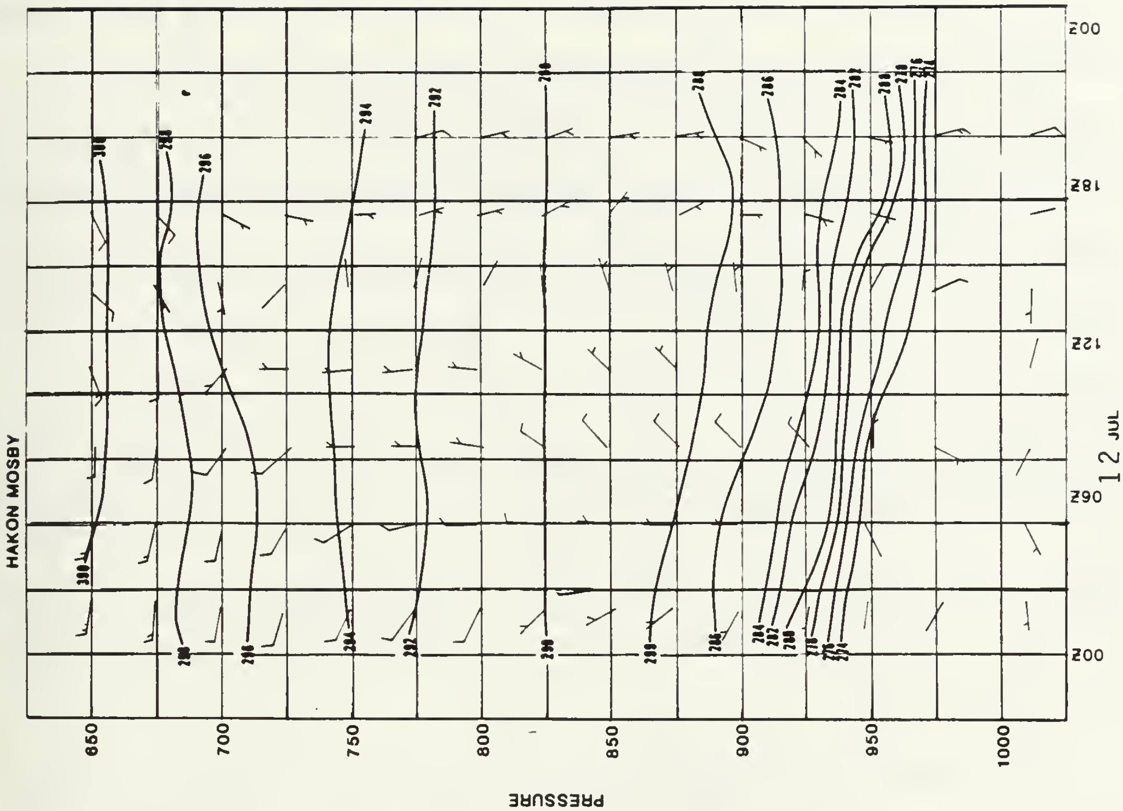


Fig. 43. Vertical Time Series for the Hakon Mosby

the wind shift occurring about 4 hours after the Hakon Mosby. The 288 °K isentrope continues to drop until just after 200 GMT on 13 July 84. The 850 mb NMC analysis for this time period shows a trough passing trough the area associated with an occluded low on the northwest coast of Greenland. This feature was not evident at other levels. This was borne out in both the cross section and the vertical time series. They both show the feature only in the lower troposphere with little or no surface manifestation. On the surface there was a significant lee trough off the east coast of Greenland but it did not migrate with the 850 mb feature.

The soundings showed two very different regions. The sounding from the Valdivia showed the results of more moisture and mixing. The atmosphere was conditionally unstable from the surface up to 950 mb. This was the base of an inversion with the air remaining very stable up to 800 mb, then a more standard condition for the rest of the sounding. The air was saturated up to 850 mb and the tropopause was at 250 mb.

The other soundings were dryer and more stable. A very strong inversion extended from 1000 mb to 900 mb in the Hakon Mosby's sounding. The inversion only extended up to 950 mb at the Polar Queen's location. The Polar Queen's sounding also exhibited what appears to be a frontal

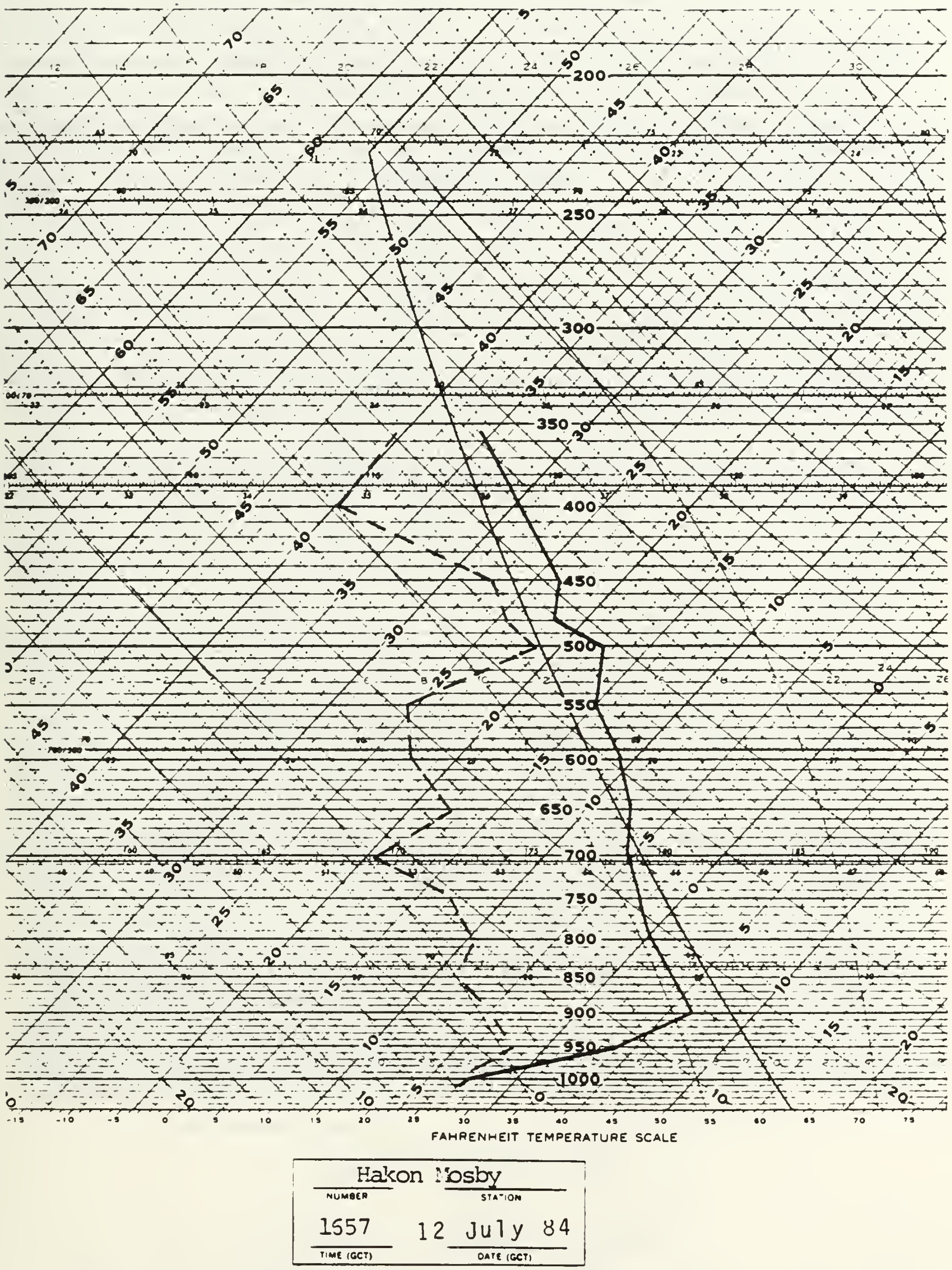
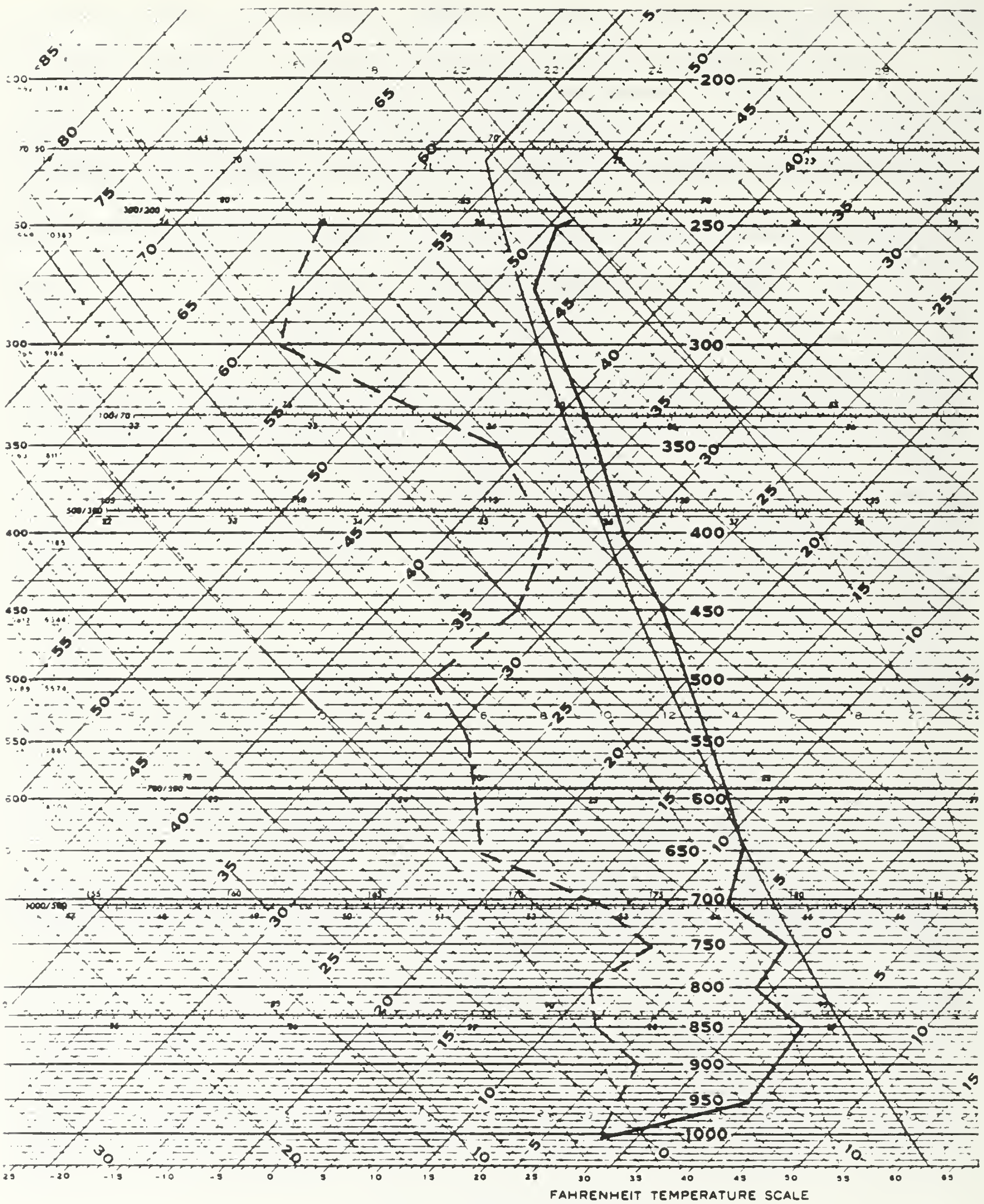


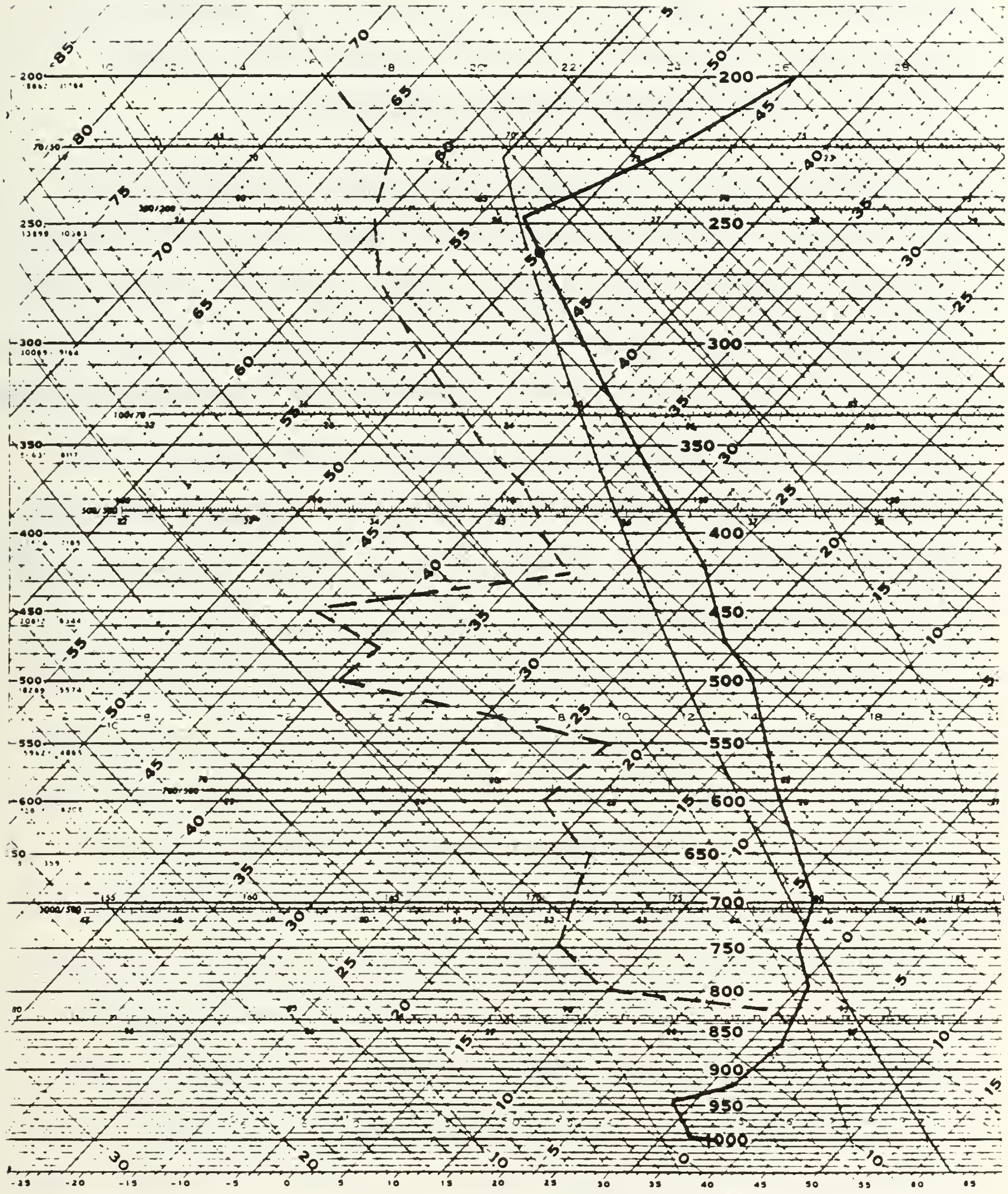
Fig. 44. Sounding From the Hakon Mosby



Polar Queen
NUMBER STATION

1656 12 July 84
TIME (GCT) DATE (GCT)

Fig. 45. Sounding From the Polar Queen



Valdivia		
NUMBER		STATION
1651	12 July 84	
TIME (GCT)		DATE (GCT)

Fig. 46. Sounding From the Valdivia

inversion from 800 to 750 mb. The air was conditionally unstable for approximately 50 mb either side of the inversion.

This section has documented in as much detail as possible the meteorological conditions of the MIZ during different synoptic conditions. When studying the MIZ the need to augment the existing WMO observing network was established by the difference between the reanalyzed surface analyses and the NMC surface analyses based only on the existing network of observing stations. The MIZ does not appear to dominate the meteorology of the region but it does have a definite effect.

V. CONCLUSIONS AND RECOMMENDATIONS

This thesis has documented the meteorological conditions of MIZEX-84. There still needs to be much more analysis of these data to try to establish why these conditions existed. More analysis may also clarify the MIZ's role in producing the conditions.

From section III, movement of synoptic scale features seems dominated by the upper level flow. During periods when the upper levels were dominated by high pressure the surface was dominated by high pressure systems as well. This forced the storms to travel along the storm tracks suggested by climatology. When the pattern shifted and upper level lows moved over the region, the path was clear for storms to travel into or through the straits. These storms depart significantly from the climatological storm tracks moving to the north northwest in three out of four of the documented cases.

The MIZ appears to play a significant but not dominant role in the meteorology of the area. The climatological storm tracks are parallel to the MIZ. Of the storms which entered the area of the experiment, one traveled parallel to the MIZ, and two slowed as they transited the MIZ. The fourth filled in the MIZ. Although not documented in this thesis the climatology also shows cloud amount contours tend to align themselves with the ice edge.

Another peculiarity about the polar region is the mechanism by which the storms move. The occluded lows transiting the area have already moved across the jet stream and are in the cold air north of the jet. In the absence of other forcing these storms will still travel 7-10 m/s in a north or north-northwest direction.

There are still many questions which are left unanswered. In the third case the wind was from the south flowing onto the ice. Is the structure of the atmosphere significantly different in a case of north wind? A topographically induced cyclone was observed during the experiment. Are there times when an upper level perturbation enters the area and causes a topographically induced cyclone to move away from the coast? Do the strong gradients of the MIZ then enhance the strengthening of the cyclone? Is the MIZ important in producing observed mesoscale vorticies or is it purely a barrier effect? These questions and many more deserve investigation in order to improve our understanding and forecasting capability in the Marginal Ice Zone.

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